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Summary of the Maritime Force Protection Technology Demonstration Project Underwater Threats Component Build 1 Trial

Anna Crawford
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DRDC Atlantic

Dana Maxwell
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Technical Memorandum
DRDC Atlantic TM 2009-070
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Canada

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Work undertaken as part of the Maritime Force Protection Technology Demonstration Project, Adrian Hewitt Project Manager.

Abstract

The Maritime Force Protection Technology Demonstration Project (MFP TDP) is on-going at DRDC Atlantic with the objective of providing advice to the CF on force protection issues by examining requirements, state-of-the-art solutions and capability gaps, while conducting a series of tests and evaluations on developmental and COTS equipment. The Underwater Threats (UW) Component focuses on addressing deficiencies in current CF capabilities for countering underwater threats to Canadian ships in harbours and anchorages. The UW Component program is designed as a series of three Builds, each including a trial, incorporating incremental improvements using a spiral development approach. The first Build trial was completed at CFB Shearwater, Fleet Diving Unit (Atlantic), in October 2008. This was the first field test of an integrated capability that includes a QinetiQ Cerberus diver detection sonar (DDS) purchased as part of the project, and a response boat outfitted with a tactical navigation display and high-frequency identification sonar for investigating targets tracked by the DDS. A major accomplishment during the trial was achievement of complete detect-to-reacquire sequences where a target was tracked by the DDS, the track location was transferred to the response boat tactical display via wireless network, and that target was reacquired with the response boat identification sonar. During exercises with divers, an underwater loud hailer was deployed after contact acquisition, a warning was issued and diver response observed. A comprehensive acoustic environmental data set was obtained during the trial which will allow further development of a DDS performance prediction tool which is also a component of the integrated capability under development.

Résumé

Le projet de démonstration de technologie de protection de la Force navale (PDT PFN) se poursuit à RDDC Atlantique en vue de la prestation de conseils aux FC sur des questions de protection des forces au moyen d'un examen des besoins, des solutions de pointe et des lacunes en matière de capacités, le tout pendant la conduite d'une série d'essais et d'évaluations sur l'équipement de développement et l'équipement commercial courant. Le volet des menaces sous-marines porte principalement sur les lacunes dans les capacités actuelles des FC pour contrer les menaces sous-marines à l'égard des navires canadiens à un port ou à un mouillage. Le sous-programme du volet des menaces est conçu comme série de trois constructions, dont chacune comprend un essai, en vue de l'intégration d'améliorations progressives en vertu d'une approche de développement en spirale. Le premier essai de construction a été complété à la BFC Shearwater, avec la coopération de l’Unité de plongée de la Flotte (Atlantique) (UPF[A]), en octobre 2008. Il s'agissait du premier essai sur le terrain d'une capacité intégrée comportant un sonar de détection de plongeurs Cerberus, de QinetiQ, acheté dans le cadre du projet, et une embarcation d'intervention munie d'un affichage de navigation tactique et d'un sonar d'identification à hautes fréquences servant aux enquêtes sur les cibles poursuivies par le sonar de détection de plongeurs. Une importante réalisation effectuée durant l'essai a été l'exécution au complet des séquences comprises entre la détection et la réacquisition lorsqu'une cible était poursuivie par le sonar de détection de plongeurs, l'emplacement de la piste a été transféré à l'affichage tactique de l'embarcation d'intervention au moyen d'un réseau sans fil, et la cible a été réacquise à l'aide du sonar d'identification de l'embarcation d'intervention. Durant les exercices menés avec des plongeurs, un mégaphone sous-marin a été déployé après l'acquisition d'un contact, un avertissement a été donné, et la réaction des plongeurs a été observée. Durant l'essai, on a obtenu un jeu complet de données environnementales acoustiques qui permettra le perfectionnement d'un outil de prédiction de la performance du sonar de détection de plongeurs, ce qui constitue aussi un volet de la capacité intégrée en voie de développement.

Executive summary

Summary of the Maritime Force Protection Technology Demonstration Project Underwater Threats Component Build 1 Trial

Anna Crawford; D. Vance Crowe; David Hopkin; Dana Maxwell; DRDC Atlantic TM 2009-070; Defence R&D Canada – Atlantic; June 2009.

Introduction or background: The Underwater Threats Component of the Maritime Force Protection Technology Demonstration Project (MFP TDP) focuses on addressing deficiencies in current CF capabilities for countering underwater threats to Canadian ships in harbours and anchorages. The threats being considered include divers (aided, unaided, open- and closed-circuit), swimmers and AUVs. The UW Component program is designed as a series of three Builds, each including a trial and incremental improvements to an integrated demonstration system for underwater force protection that incorporates COTS and developmental equipment.

Results: The first Build trial was completed in October 2008 at CFB Shearwater with the cooperation of Fleet Diving Unit (Atlantic). The goals of the trial were to demonstrate the newly acquired QinetiQ Cerberus diver detection sonar (DDS) in an operational setting, to acquire comprehensive environmental measurements to allow further development of acoustic performance prediction capability and to field test a response boat contact reacquisition and identification capability. All of the trial objectives were met.

Significance: A major accomplishment achieved during the trial was successful reacquisition of targets following initial detection and tracking by the DDS, transfer of track locations to the response boat tactical display via wireless network, response boat transit to that location and deployment of the identification sonar. Exercises with divers were conducted, during which an underwater loud hailer was deployed following target reacquisition and instructions issued. This demonstrates in principle the integrated detection and response system under development. The environmental data set collected will allow continued development of a DDS performance prediction tool based on acoustic propagation modeling that requires environmental data for input.

Future plans: The experience gained through field testing of the integrated system during the Build 1 trial will provide valuable insights into the improvements necessary to continue the program of development in a productive manner. This will feed directly into preparations for the subsequent Build.

Sommaire

Summary of the Maritime Force Protection Technology Demonstration Project Underwater Threats Component Build 1 Trial

Anna Crawford; D. Vance Crowe; David Hopkin; Dana Maxwell; DRDC Atlantic TM 2009-070; R & D pour la défense Canada – Atlantique; Juin 2009.

Introduction ou contexte : Le projet de démonstration de technologie de protection de la Force navale (PDT PFN) porte principalement sur les lacunes dans les capacités actuelles des FC pour contrer les menaces sous-marines à l'égard des navires canadiens à un port ou à un mouillage. Les menaces à l'étude comprennent des plongeurs (assistés, non assistés, en circuit ouvert et en circuit fermé), des nageurs et des véhicules sous-marins autonomes (AUV). Le programme du volet des menaces sous-marines est conçu comme une série de trois constructions, dont chacune comprend un essai, en vue de l'intégration d'améliorations progressives à un système de démonstration visant la protection sous-marine de forces qui intègre de l'équipement de développement et de l'équipement commercial courant.

Résultats : Le premier essai de construction a été complété en octobre 2008 à la BFC Shearwater avec la coopération de l'Unité de plongée de la Flotte (Atlantique) (UPF[A]). Il visait à faire la démonstration du sonar de détection de plongeurs Cerberus, nouvellement acquis de QinetiQ (sonar de détection de plongeurs), dans un milieu opérationnel, en vue de l'acquisition de mesures environnementales exhaustives dans le but de permettre le perfectionnement d'une capacité de prédiction de la performance acoustique et de mettre à l'essai sur le terrain une capacité d'identification et de réacquisition de contacts à l'aide d'une embarcation d'intervention. Tous les objectifs de l'essai ont été atteints.

Importance : Une réalisation importante effectuée durant l'essai a été la réacquisition réussie des cibles après leur détection initiale et leur poursuite par le sonar de détection de plongeurs, le transfert de l'emplacement des pistes à l'affichage tactique de l'embarcation d'intervention au moyen d'un réseau sans fil, le passage de l'embarcation d'intervention à l'emplacement des pistes et le déploiement du sonar d' identification. Des exercices ont été menés avec des plongeurs, un mégaphone sous-marin a été utilisé durant les exercices après la réacquisition des cibles et des instructions ont été données, ce qui démontre en principe le système intégré de détection et d'intervention déployé. La série de données environnementales recueillies permettra le perfectionnement d'un outil de prédiction de la performance du sonar de détection de plongeurs d'après une modélisation de la propagation acoustique qui requiert des données environnementales à l'entrée.

Perspectives : L'expérience acquise lors de la mise à l'essai du système intégré sur le terrain durant le premier essai de construction donne des connaissances utiles des améliorations qu'il faut apporter pour poursuivre le programme de perfectionnement de façon productive, ce qui se répercutera directement sur les préparatifs à l'étape subséquente de construction.

Table of contents

List of figures

List of tables

Acknowledgements

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1 Introduction

The Maritime Force Protection Technology Demonstration Project (MFP TDP) is a 4-year program now in its third year. It has been divided into four Components: 1) Command-and-Control (C2) and Integration, 2) Vulnerability and Recoverability, 3) Surface Threats and 4) Underwater Threats. The Underwater (UW) Threats Component focuses on addressing deficiencies in the current CF capabilities for countering underwater threats to Canadian ships in harbours and anchorages. The threats being considered include divers (aided, unaided, open and closed-circuit breathing apparatus), swimmers and Autonomous Underwater Vehicles (AUVs). The UW Component program is a series of three Builds incorporating incremental improvements in capability using a spiral development approach, increasingly integrating capabilities from all four project components. Each Build includes a trial and the first Build trial was conducted in September-October of 2008.

A major part of the early MFP TDP Build 1 effort was the procurement of a commercial-off-the-shelf Diver Detection Sonar (DDS). Following a series of four 1-week-long DDS demonstrations held at CFB Shearwater in December 2006 and March 2007, a process of bid evaluations led to purchase of a Cerberus DDS system supplied by QinetiQ, UK. This sonar was delivered in August 2008 and was deployed for the duration of the Build 1 trial.

The trial was scheduled from September 17 to October 17, 2008, at CFB Shearwater. Divers from the Fleet Diving Unit (Atlantic) were instumental in deployment and recovery of equipment and performed planned swim routes during the last week of the trial. The schedule of events during the trial is detailed in Section 3. Later sections provide overviews of the environmental measurements that were made, response boat and diver detection sonar operations, a brief summary of post-trial associated activities and finally, some recommendations arising from the trial experience.

2 Trial Objectives

The objectives of the Build 1 trial were summarized in the Build 1 Trial Plan [1] in three areas:

1. Demonstrate DDS operational usage – Through the duration of the trial, the DDS was operated in a realistic harbour environment. This provided invaluable experience and a data set for follow-on research. The QinetiQ Cerberus DDS was newly acquired and some effort was required in training operators that can continue with the system through the MFP TDP in the follow-on Builds. Diver runs were planned during the trial that tested aspects of DDS performance, such as in areas of high clutter or, if environmental conditions were conducive, in areas where propagation conditions limit capability.

2. Through-the-sensor performance assessment – Environmental measurements were made (water temperature, sound speed and velocity) that would serve as inputs to an acoustic propagation model. The model predictions were validated by making acoustic measurements. In addition, fixed and movable targets were placed in the sonar field of view. The Slocum Glider served as both a mobile target and an environmental monitoring device. A long-term goal of the UW Component is to eventually provide operators with a real-time updating measure of DDS performance, perhaps in a geographically referenced format, i.e. highlighting regions of the sonar coverage area where detection performance is expected to be poor. As a start during the trial, a post-processing approach was taken as there was no real-time access to the environmental data.

3. Contact reacquisition and identification – In a complete detect-to-engage sequence, there is a follow-on response to an initial threat detection. During the trial period, a small response boat carrying an identification sonar was tasked to investigate targets that were detected and tracked by the DDS. Observers from the MFP TDP C2 Component assisted with observation and assessment of the response effectiveness. Three high-frequency sonars were trialed for diver identification purposes on the response boat: the Imagenex 837 and 881L and the BlueView P450.

Other trial activities supported minor objectives, such as testing and evaluation of equipment that was recently procured for the MFP TDP program, such as environmental monitoring equipment and the DDS.

Despite scheduling issues outside the project's influence, the trial objectives were met. A large quantity of environmental data was collected using a moored array of temperature sensors, three days of Webb Research Glider operations and a series of combined in-water sound velocity and transmission loss measurements across the sonar field of view. These measurements will allow further development of acoustic modeling capability. The DDS was operated over an extended period of time giving operators the opportunity to familiarize themselves. During the afternoon prior to the scheduled diver runs, there was a hardware failure in the DDS head. This meant it was not possible to observe divers swimming planned routes with the DDS, so the focus moved to response boat exercises. Earlier in the trial, "divers of opportunity" were observed with the DDS in the nearby practice area used by FDU(A) for routine diver training. During the trial, repeats of the response boat detect-to-warn sequence were successfully performed on drifting targets and divers. DDS contacts were passed by wireless network to the response boat tactical display, which were then pursued and verified using the identification sonar. During some of the diver runs near the end of the trial, the loud hailer was then used and diver response observed.

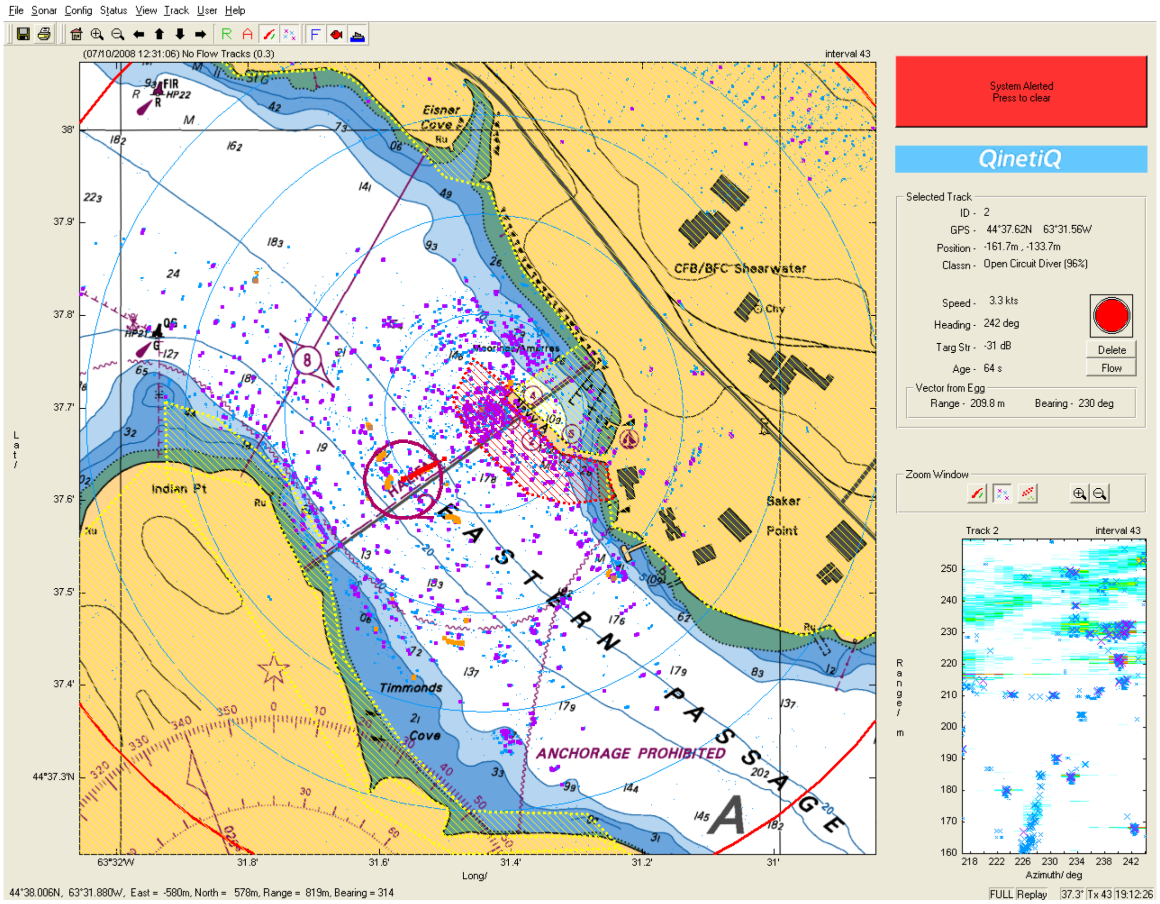


Figure 1: Screen shot of the Cerberus DDS display showing an alerted track in Eastern Passage, in the trial operating area at CFB Shearwater, Nova Scotia.

3 Schedule of Events

Trial activities at CFB Shearwater were conducted between September 17 and October 17, 2008. A calendar covering that time period is shown in Table 1. Personnel were not on-site every day through the duration of the trial.

During the first week, a 20’ container shelter was placed and hooked up on NA Jetty and the DDS was deployed. The following two weeks had sporadic activities including environmental and transmission loss measurements and DDS operations with towed targets. Some fit-out was done of response boat systems and glider operations commenced on October 2nd.

The following week was the first of two weeks of more concentrated effort, beginning with two days of glider operations and the start of on-water response boat tests. A second series of environmental and transmission loss measurements was collected late during that week. FDU(A) divers participated in the trial during the final week, after the Thanksgiving holiday. The DDS had a hardware failure during the afternoon of the day prior to the scheduled diver runs, consequently response boat exercises with the divers became the focus. The DDS deployment site was surveyed on two afternoons with a VideoRay micro-ROV and a final series of transmission loss and environmental measurements were made. The DDS was recovered and other equipment was packed ending the trial on October 17th. The container was moved off the jetty early the following week.

Table 1: Calendar of Build 1 trial events in September and October 2008.

Mon		Tues		Wed		Thurs		Fri	
15 Sep	AM	16		17	container moved, hooked up, set up	18	deploy DDS	19	
	PM						DDS test		
22	DDS on, tow targets	23	DDS on, tow targets	24	response boat fit-out	25	TL & env. meas., DDS on	26	response boat fit-out
			DDS sector 5 issue				divers rotate DDS, DDS test		
29		30		1 Oct	move response boat to FDU	2	Glider ops, DDS on	3	
					glider setup		Glider ops, DDS on		
6	Glider ops, DDS on, response boat work-up, WiMAX tests, deploy T-chain	7	Glider ops, DDS on, response boat ops.	8	response boat ops., DDS on	9	TL & env. meas., DDS on, recover T-chain	10	
	Glider ops, DDS on, spoof pings		Glider ops, DDS on						
13	Thanks-giving Holiday	14	deploy T-chain, DDS on	15	CCDA divers, response boat ops, VideoRay survey	16	CCDA divers, response boat ops., loud hailer	17	recover DDS
			response boat ops., DDS on, DDS failure		response boat ops		TL. & env. meas., recover T-chain, VideoRay survey		pack up & demobilize

4 Equipment Deployment and Recovery

The locations of deployed equipment are shown in Figure 2. All trial activities occurred in the vicinity of NA Jetty, CFB Shearwater. In the figure, the DDS location is marked “Egg”. The location of the portable container laboratory on the Jetty is marked “Container”. A thermistor chain was deployed twice during the trial, at the two locations marked “T-chain1” and “T-chain2”. The scale bar in the lower left is approximately 125 m long. The DDS field of view extends well beyond the extent of the photo and includes an area where divers from FDU(A) run practice exercises, shown in green in the figure. An approximation of the boundary of the exclusion zone that is maintained by the CF at 100 m surrounding the Jetty is shown in red in the figure. There are marker floats at two corners of the zone, also indicated in the figure.

Figure 2: Google Earth aerial photograph of the area surrounding NA Jetty, Shearwater.

4.1 Container Portable Laboratory

A 20’ container portable laboratory owned by DRDC was used as the DDS shore station and general centre for trial activities. It was moved from the DRDC compound to NA Jetty by crane and flatbed on September 17th and hooked up to power and phone services on the jetty. It was unhooked on October 17th and moved back to DRDC early during the following week. Figure 3 shows a photo of the container on the Jetty. The photo was taken prior to a wind meter and a surveillance camera being installed on the roof, however the WiMAX antenna (providing wireless network coverage in the trial operations area) can be seen above the white diamond shape on a long pole above the nearest corner of the container.

Figure 3: Portable container laboratory placed on NA Jetty, with HMCS Fredericton.

4.2 Diver Detection Sonar

The DDS was deployed with the assistance of FDU(A) divers and a crane on September 18th. The procedure partly followed instructions detailed in the Cerberus deployment manual supplied by the manufacturer [2]. Additionally, consultation with FDU(A) personnel on the safe use of lift bags was helpful as that method of moving the sonar to the deployment location is not included in the manufacturers procedures. A 3-page document describing Cerberus deployment and recovery procedures is included in Annex A. After the cable was spooled out onto the jetty, plugged into the DDS, and secured to the sonar base, the crane lifted the DDS into the water with deflated lift bags attached. A diver filled the lift bag so the sonar was floating prior to the crane releasing the load. The DDS was then towed slowly into position by the divers' safety boat while the DDS cable was paid out from the jetty. Once in position following directions from scientific staff on the jetty, the lift bag was deflated, lowering the DDS to the seabed. The DDS was checked by the divers to make sure it was sitting level on the seabed and the cable routing along the seabed back to the jetty was surveyed. The cable was lashed to the jetty at the point it met the deck surface.

Recovery of the DDS followed a similar series of events in reverse on October 17th. Figure 4 shows the divers' safety boat towing the lift bag supporting the DDS (on the left) and the crane recovering the DDS at the conclusion of the trial (on the right).

Figure 4: Sonar deployment by divers (left) and crane recovering (right).

During the first week of DDS operation, it was noted that there was a problem with the sonar transmit sector 5 not transmitting full power. This 60° sector was originally directed toward the North end of McNabbs Island, covering a significant portion of the most valuable part of the sonar field of view. It was arranged at short notice with the FDU(A) divers to rotate the DDS so that sector 5 was directed toward the jetty. This was done on September 25th. Later, the sector 5 issue was diagnosed as a software problem and subsequently fixed with a version update.

Figure 5: Preparing the Cerberus "Blue Egg" for deployment.

4.3 Other Equipment

A small mooring made of temperature-depth loggers was hand deployed and recovered from the Zodiac work boat twice during the trial at locations shown in Figure *2*. A wind gauge and surveillance camera were mounted on the roof of the 20' container, along with the WiMAX radio. It was originally planned to deploy an Acoustic Doppler Current Profiler (ADCP) in Eastern Passage for the duration of the trial, however that piece of equipment was damaged during its previous use at sea and was not serviceable. No other equipment requiring multi-day deployment or recovery was used during the trial. The Slocum Glider (shown in Figure 6 and see Section 5.2) and the transmission loss and sound velocity profile measurements (see Section 5.3) used the Zodiac work boat for support.

Figure 6: Webb Research Slocum glider surfaced at a waypoint.

5 Environmental Measurements

5.1 Weather

The period September 14th to October 18th, 2008, had typical fall weather at CFB Shearwater. Figure 7 and Figure 8 show plots of air temperature and wind speed logged in September and October by the Environment Canada weather station located on NA Jetty[1], and tides measured by the Department of Fisheries and Oceans Halifax Harbour tide station[2]. Air temperature averaged 15°C in September and 10°C in October. Winds were generally stronger in October. The tidal range is about 2 m from highest high tide to lowest low tide. There are short gaps in the weather station record on September 24th and October 6th, and in the tidal record on September 26th-27th, while the weather or tide sensors were out of service.

Operations were not unduly affected by weather on any occasion during the trial in that there were no weather related cancellations of planned activities. The glider was affected by strong winds and wind-driven surface currents (see discussion in Section 5.2). Response boat operations were also affected when winds were strong as it became difficult to maneuvre and to hold a position.

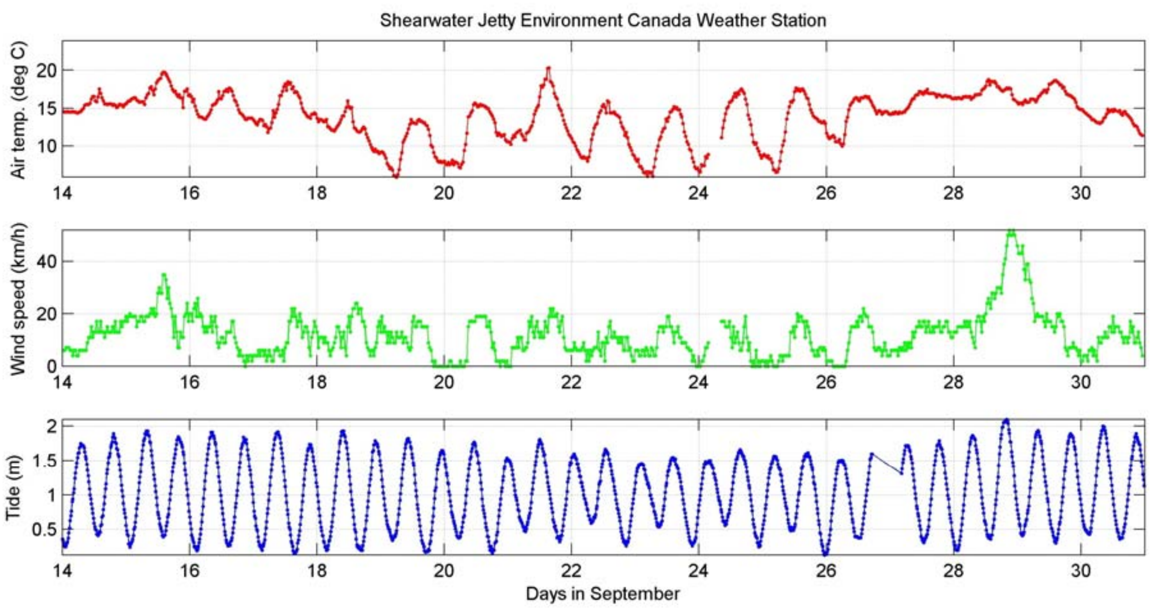


Figure 7: Air temperature and wind speed at Shearwater and Halifax tide, September 2008.

[1] www.climate.weatheroffice.ec.gc.ca
[2] www.meds-sdmm.dfo-mpo.gc.ca, station number 490.

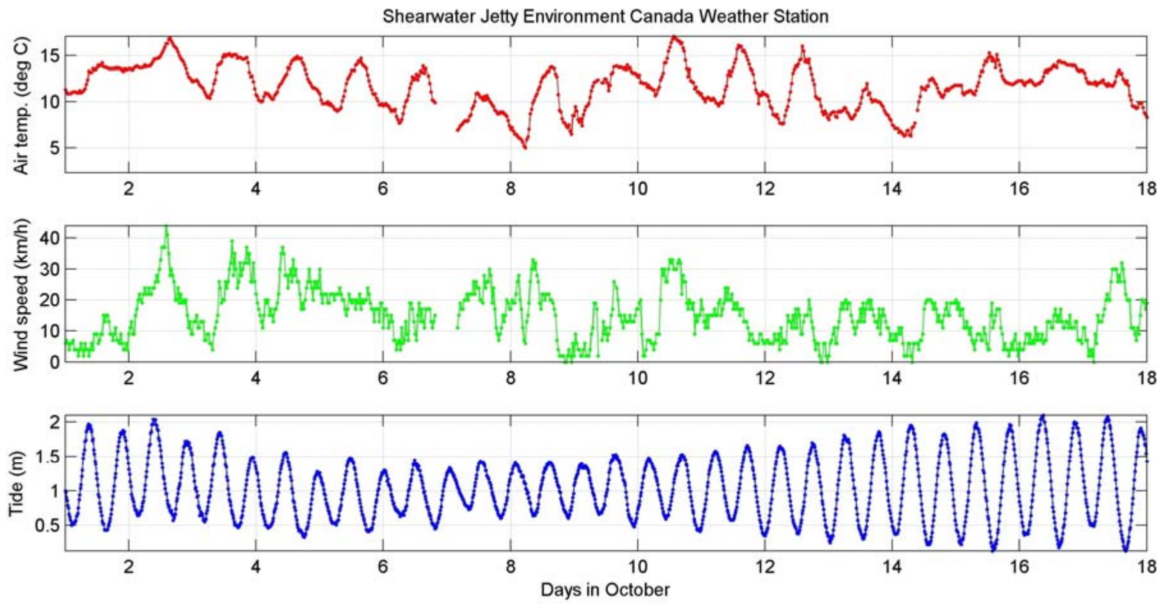


Figure 8: Air temperature and wind speed at Shearwater and Halifax tide, October 2008.

Wind is the dominant weather factor affecting short term changes in local water properties in Eastern Passage. Wind-driven circulation moves colder or warmer water masses into the Passage or mixes the water column to remove warm surface stratification caused by solar heating. The strongest winds are predominantly from the North-West, as shown by the wind compass plots in Figure 9 (vectors show wind direction “toward”, rather than “from”). During a previous trial at Shearwater, for the month of March 2007 an Acoustic Doppler Current Profiler (ADCP) was deployed in Eastern Passage. This data record showed that when winds are from the North-West, significant wind-driven currents matching wind direction develop in the surface waters. There is a lesser tendency for current forcing by winds from the South-East, and virtually no tendency for currents to be formed by cross-channel winds. The narrowness of the channel and the surrounding topography do not allow winds to effectively develop water currents in the cross-channel direction.

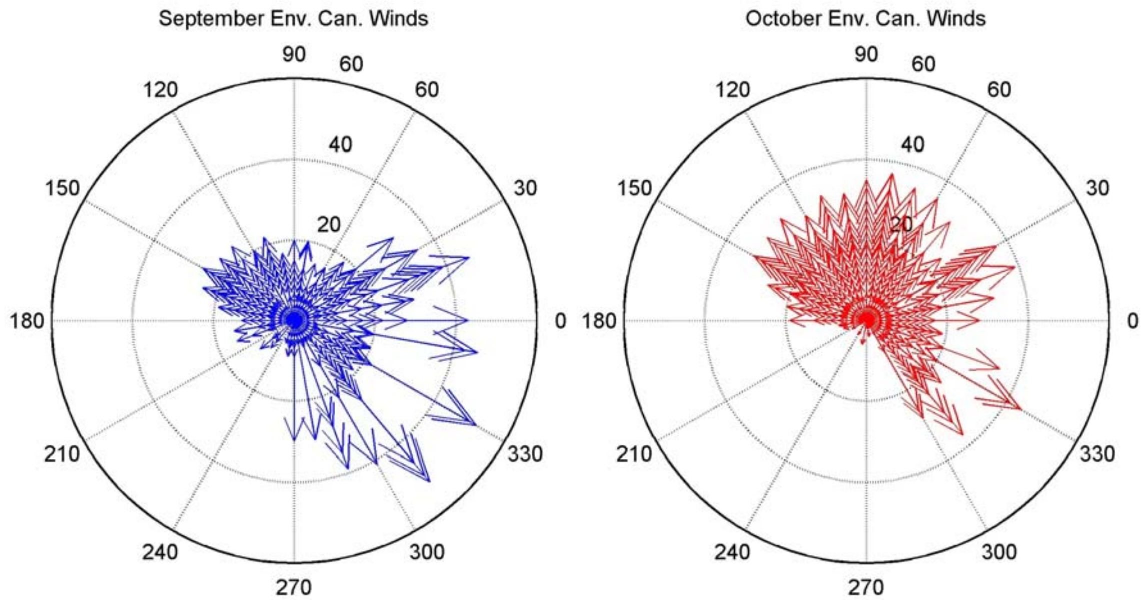


Figure 9: Wind direction vectors (length in m/s) for September (left) and October (right) at Shearwater. Toward North is up and toward East is to the right.

5.2 Glider Operations

The Webb Research Slocum Glider is a small AUV that uses buoyancy control to move vertically through the water. It glides forward using small wings to follow a vertical zigzag path between upper and lower depth limits and between programmed geographic or timed waypoints. It uses GPS positioning while surfaced and it can also telemeter logged data at those times using Iridium phone or wireless network. It is equipped with a Seabird conductivity-temperature-depth (CTD) instrument to measure water properties while under way. It navigates by dead reckoning between waypoints and has some rudimentary capability to correct for currents.

The glider was deployed to measure water properties on three days during the trial, October 2nd, 6th and 7th. It was usually programmed to glide up and down the centre of Eastern Passage in a series of 20-minute-long legs. Figure 10 to Figure 12 show the end points of the legs travelled on the three deployment days with circle markers at the end positions, just before diving and surfaced at the end of each leg. The numbers in red indicate the leg number at the start position of each leg.

Glider operations were affected by wind and wind-driven currents. On October 2nd, winds were from the South-East and the leg end points show the glider is pushed North-West while surfaced between legs. On October 7th, the route that was programmed was intended to have transects up and down Eastern Passage passing increasingly close to the DDS to test detection capability, however the wind and wind-driven surface current were strong enough from the North-West that while at or near the surface, the glider could not make headway up the Passage into the wind. The glider was retrieved and restarted at the North-West end of the Passage for leg 15, and the plan of having passes increasingly closer to the DDS had to be abandoned due to time constraints.

Due to its size and slow forward speed, about 1 knot, the glider can also serve as a diver-like target for the DDS. During the trial, however, the DDS tracker was not effective in establishing a track, even though sonar hits on the glider were sometimes visible to the operators on the sonar display. The apparent size of the glider to the DDS is aspect dependant and the best detection probability would be expected with the glider roughly at broadside to the sonar. It is possible that the vertical motion of the glider through the water column prevented the sonar from establishing consistent enough contact over time to trigger the tracker to alert status. In any case, tracking of the glider by the DDS was not successful in general.

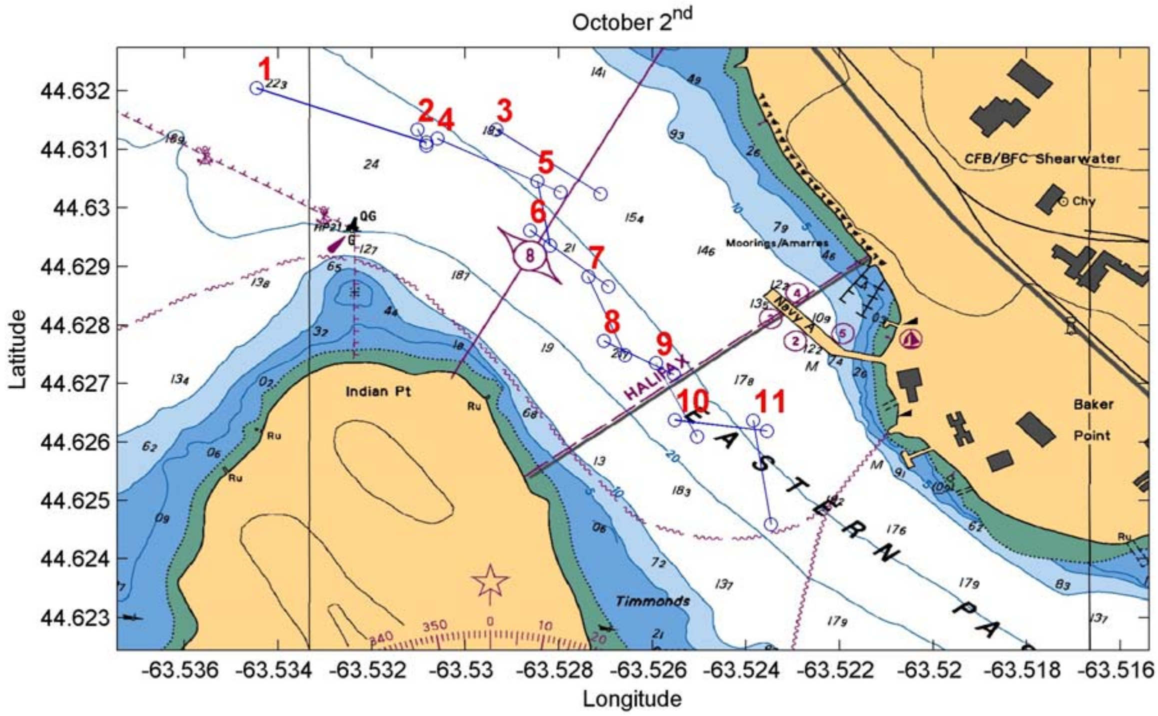


Figure 10: Start and end positions of glider legs in Eastern Passage on October 2nd. Legs are numbered in red at the start positions.

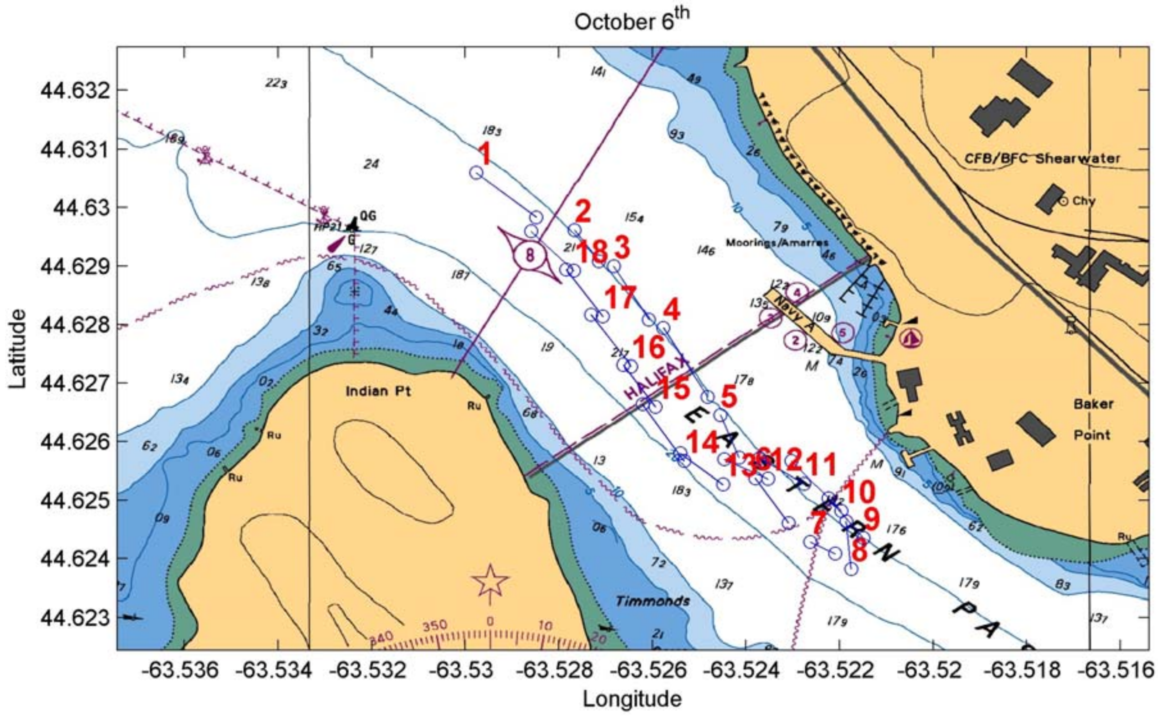


Figure 11: Glider legs on October 6th.

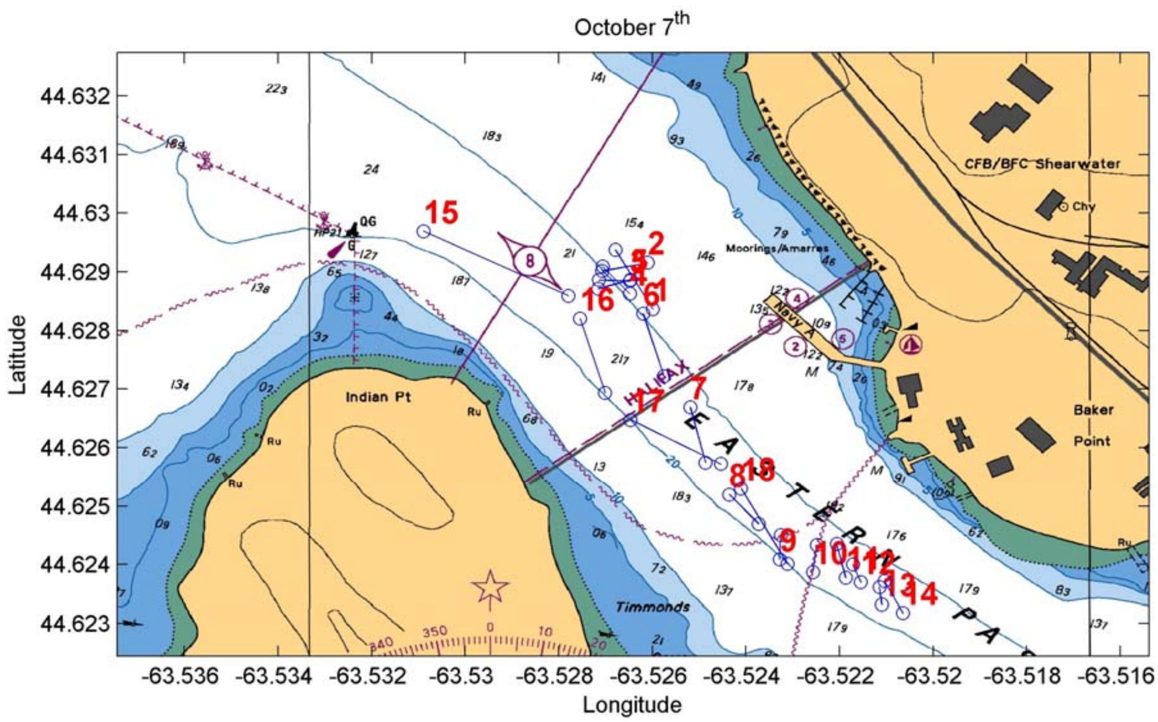


Figure 12: Glider legs on October 7th.

Figure 13 to Figure 15 show plots of colour-coded water temperature along approximate zigzag tracks followed by the glider through the water column on the three days. Horizontal positions are interpolated between the end points of each leg, plotted against the measured pressure along the path, converted to depth. There is a large change in the vertical water temperature profile between October 2nd and October 6th. The water is warmer overall on October 2nd by about 10°C and the warm surface water layer extends almost to the bottom. By October 6th and 7th, this warm water has either been cooled, or more likely moved aside by cooler water. There is some surface heating creating a warmer surface layer, which has extended further downward between October 6th and 7th. The water temperature profiles collected by the glider are compared with other independent water temperature measurements in Section 5.5.

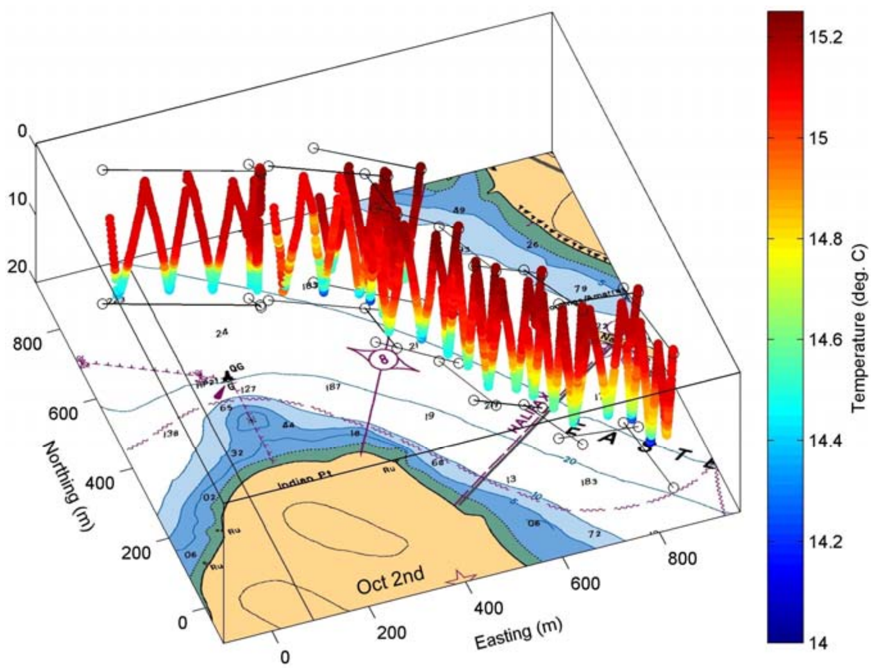


Figure 13: Colour coded water temperature following the approximate path of the glider in Eastern Passage on October 2nd.

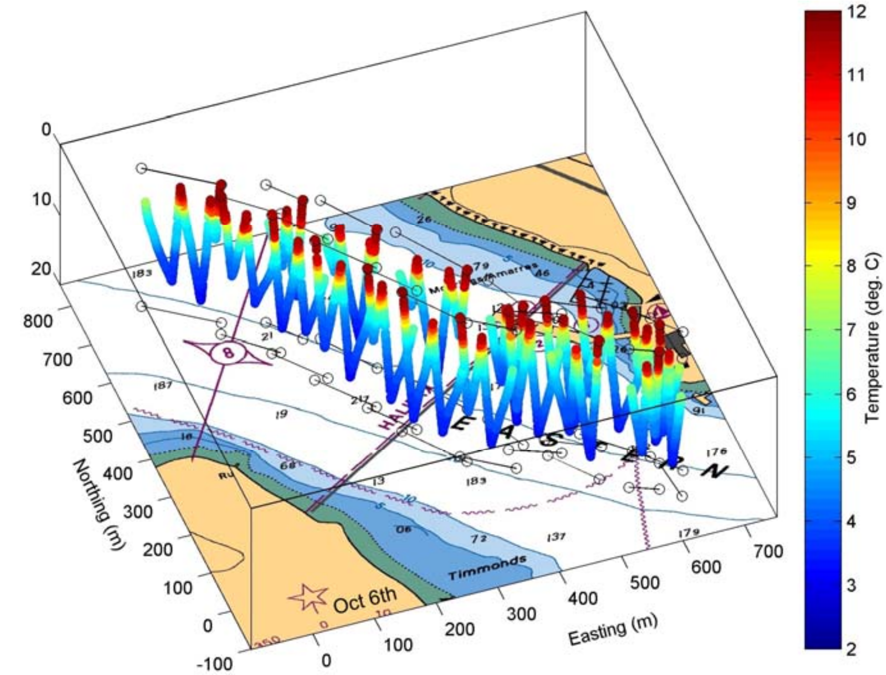


Figure 14: Colour coded water temperature along the approximate path followed by the glider, October 6th.

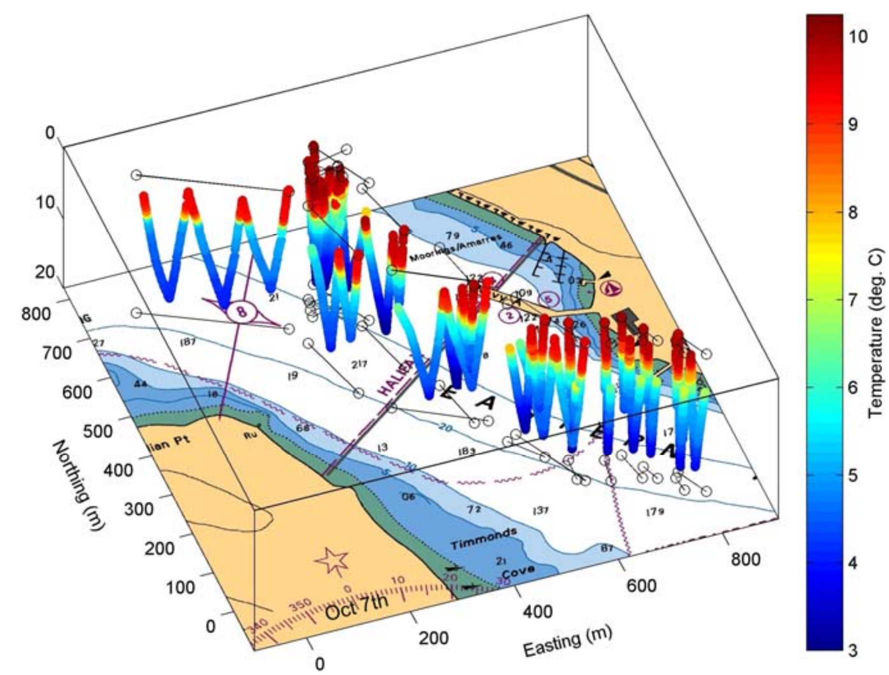


Figure 15: Colour coded water temperature along the approximate path followed by the glider, October 7^{th}.

5.3 Sound Velocity and Transmission Loss Measurements

Several series of measurements were made of acoustic transmission loss along with vertical profiles of sound velocity and water temperature on September 25th, October 9th and 16th. An additional set of temperature and sound velocity measurements were made on October 2nd.

The transmission loss measurements were made using a pair of Reson TC4014-1 hydrophones, and the sound velocity and temperature profiles were measured using an Applied Microsystems Ltd. (AML) SV Plus V2. Position was logged using a Garmin 76 handheld GPS.

Figure 16 to Figure 19 show the measurement locations on the four days. The intention was to make sets of measurements at locations along radials centred on the DDS for use as inputs to the acoustic propagation model and for comparison with model predictions. Two radials were chosen on September 25th, one to the West and another to the North-West. The measurements made on October 2nd were taken at locations along the centre of Eastern Passage and were intended for comparison with the glider measurements. A single radial was chosen for the measurements on October 9th and the same locations were visited on October 16th.

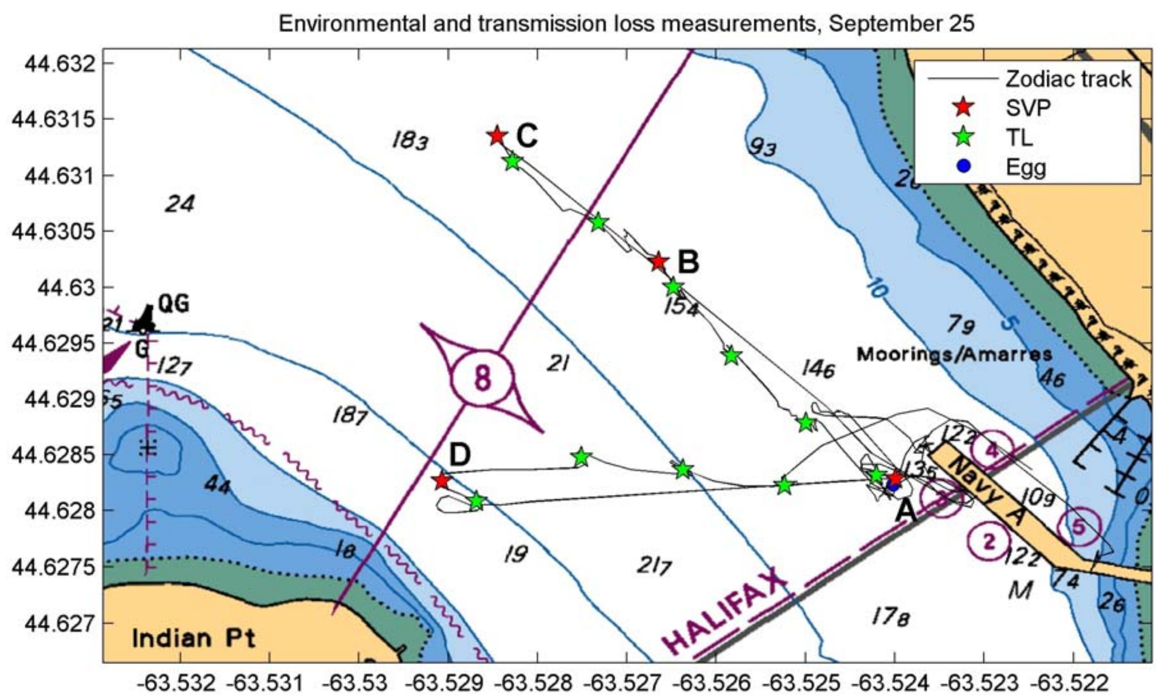


Figure 16: Environmental measurement locations, September 25th.

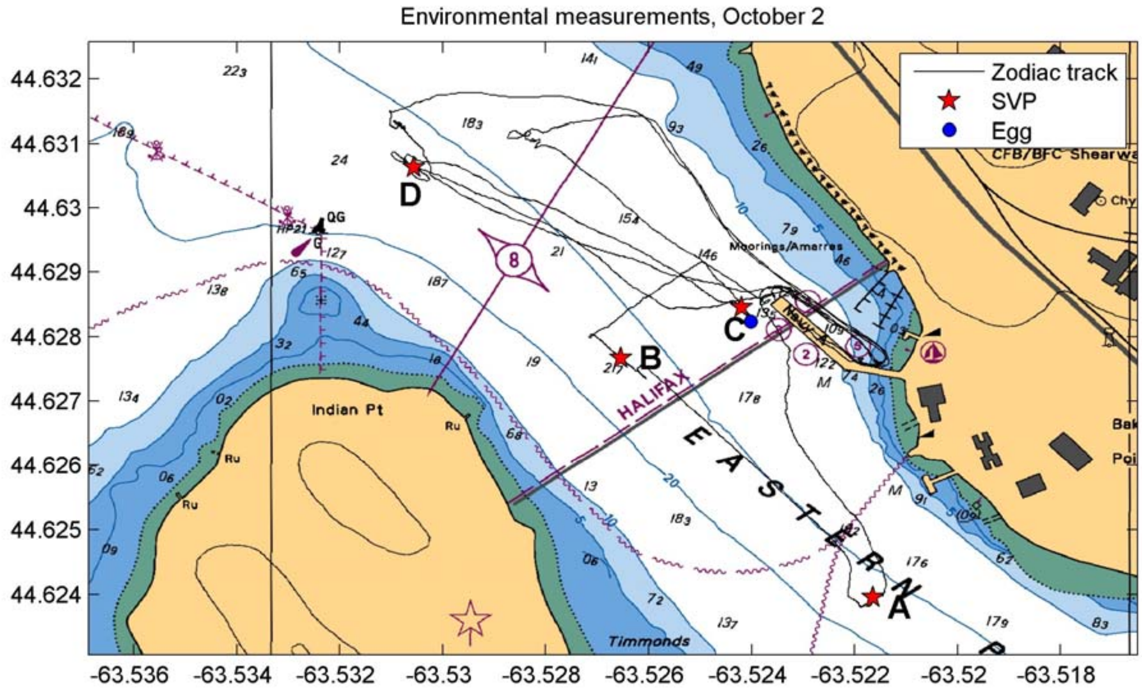


Figure 17: Environmental measurement locations, October 2nd.

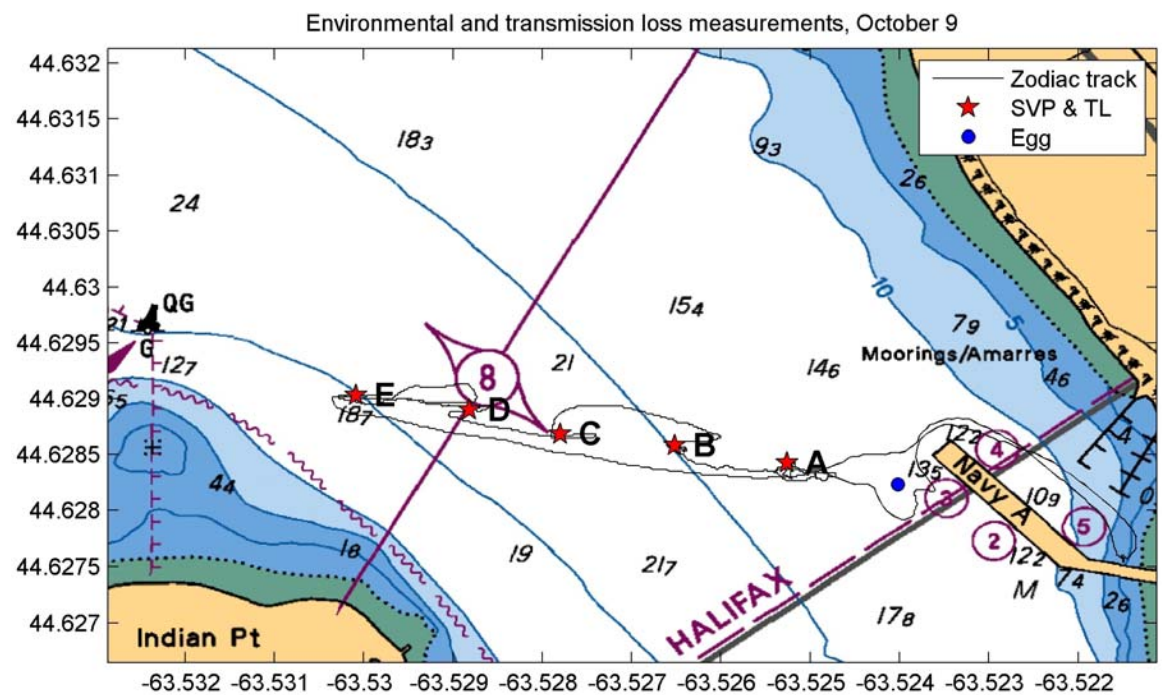


Figure 18: Environmental measurement locations, October 9th.

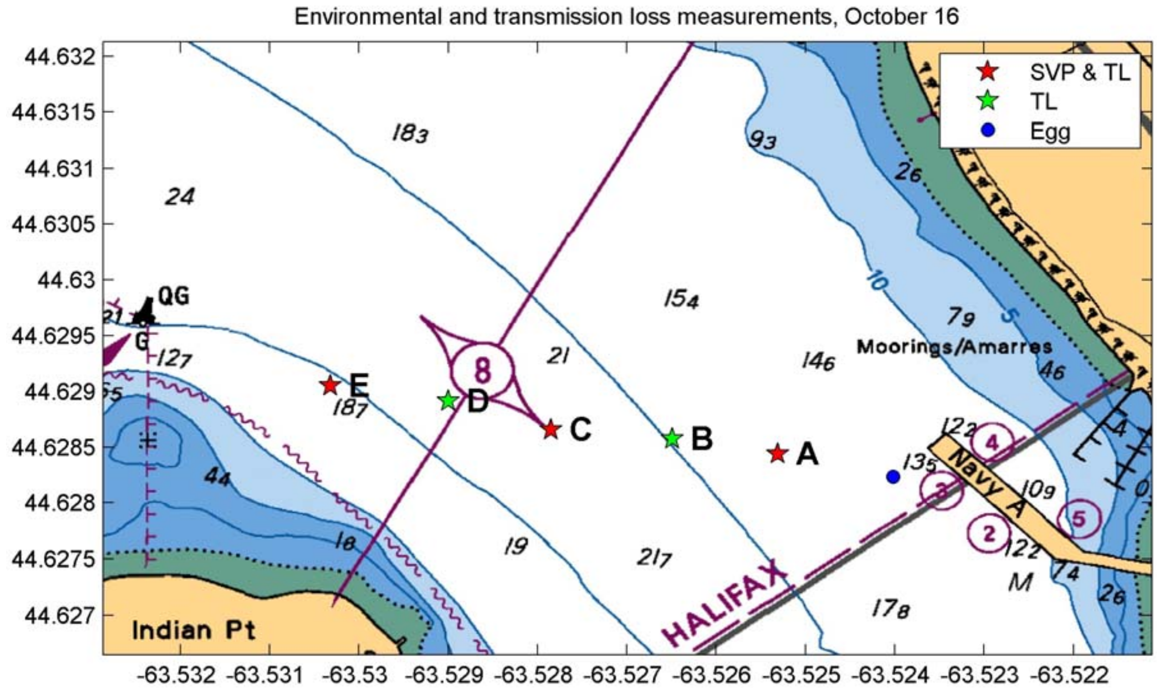


Figure 19: Environmental measurement locations, October 16th.

Comparisons between the various temperature measurements are very good. This is described in Section 5.5.

Transmission loss measurements were made to compare with the results of acoustic propagation loss modelling which would be done post-trial with the measured sound velocities as input. Figure 20 shows examples of single pulses recorded on October 16th at five locations, A through E, which are shown in Figure 19. The duration of the original transmit pulse is shown between vertical dashed lines in Figure 20. The plot shows filtered signal amplitudes which have had high frequency content removed to show the shape of the received pulse and are shifted in time to align the start of the pulses. The measurement locations are nominally 100 m apart and the attenuation of the acoustic signal with range is clearly evident. The DDS hardware failure on October 14th affected the receiver, not the transmitter, as verified by the measurements made on October 16th.

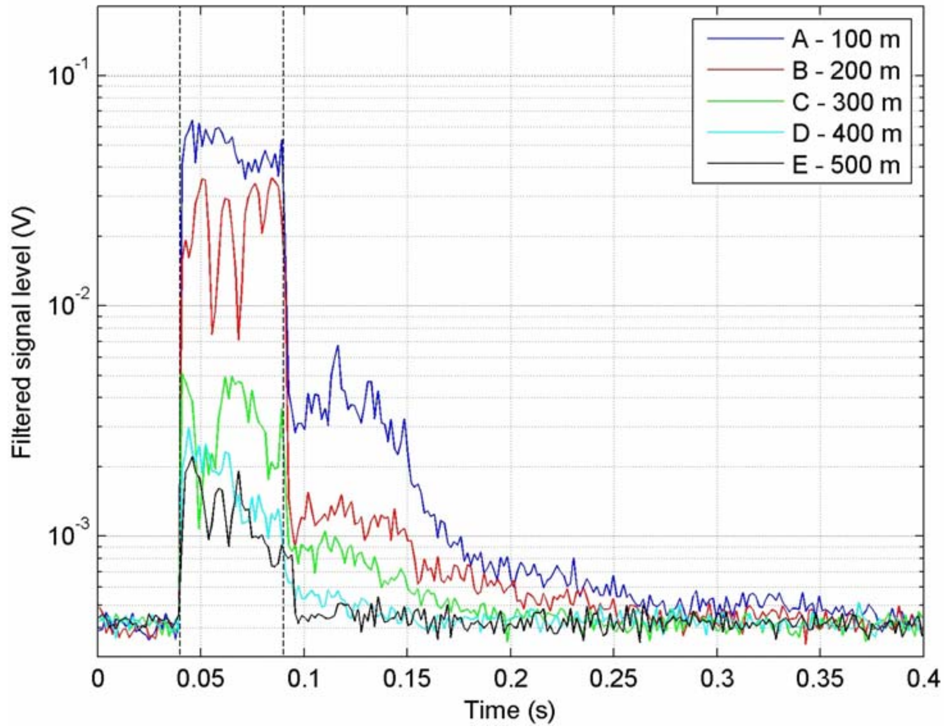


Figure 20: Transmit pulses measured at the five locations shown in Figure 19

5.4 Thermistor Chain

A thermistor chain mooring was made from a collection of eight Vemco temperature and four RBR temperature-depth mini-loggers. The Vemco loggers were on loan from Bedford Institute of Oceanography and the RBR loggers from Dalhousie and Memorial Universities equipment pool. These are small self-contained instruments with programmable sampling duration and rate. The mooring was constructed by tie-wrapping and taping the loggers to a length of negatively buoyant nylon line with a surface float and bottom anchor weight. The length of line was 25 m, with sensor spacing varying along the length from 1 m at the surface to 3 m at the bottom. The mooring was deployed in 15-17 m water depth, about 50 m South-East of the DDS (see Figure 2), and was designed to hang downward from the surface float. The lowest sensor was resting on the seabed except when surface currents and wind were pulling the line taut. The depth logging RBR sensors were distributed along the line to monitor sensor vertical positions in the water column. This mooring was constructed to be a temporary stand-in for COTS equipment which has not yet been procured for the MFP TDP but is planned to provide real-time environmental monitoring capability to feed into the DDS performance prediction modeling tool.

The thermistor chain was deployed twice, from late morning October 6th to late morning October 9th and from late morning October 14th to early afternoon October 16th. The sensors were programmed to record at 30 second intervals. Figure 21 and Figure 22 show plots of colour-coded temperature vs. depth and time for the two deployments. The first deployment overlaps two days of glider operations, October 6th and 7th. The vertical temperature structure is consistent between the glider and thermistor measurements, showing a warmer surface layer that is slowly mixed in and eroded over three days. The second deployment shows a significant warming of the water over two days.

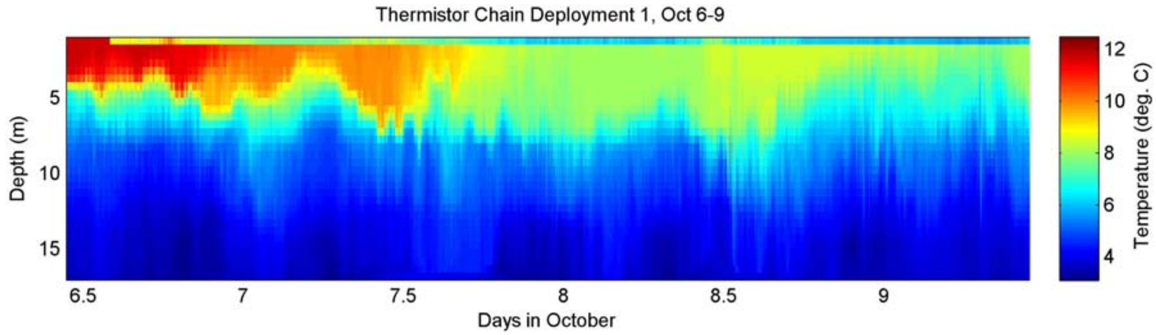


Figure 21: Water temperature vs. depth and time for the first thermistor chain deployment, October 6th to 9th.

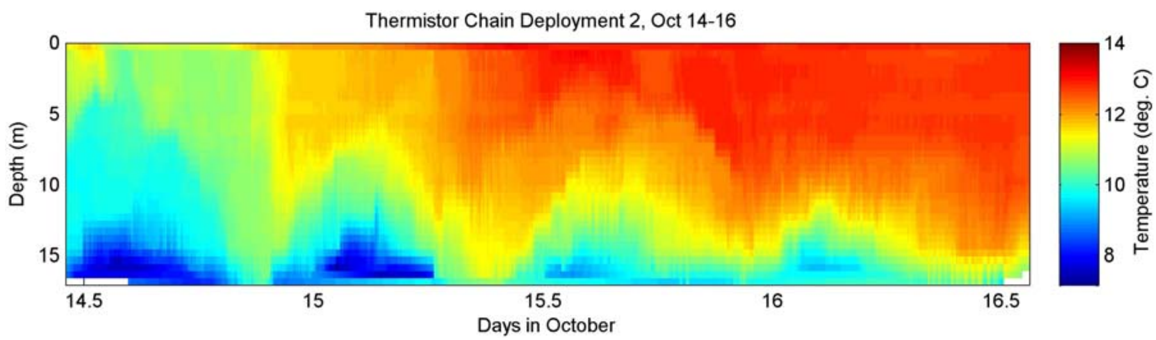


Figure 22: Water temperature vs. depth and time for the second thermistor deployment, October 14th to 16th.

5.5 Comparison of different water temperature measurements

Measurements were made of water column temperature, the dominant factor in determining sound velocity, using an AML profiler, a Seabird CTD instrument on a glider and a moored set of thermistor temperature loggers. Figure 23 shows a comparison of water temperature profiles measured in October. The locations of the AML profiler measurements on October 2nd, 9th and 16th, labelled A through E, were shown in Figure 16 to Figure 18. These are compared with glider profiles collected during the same time interval on October 2nd and with the thermistor chain mooring data on October 9th and 16th. The glider tracks are shown in Figure 10 to Figure 12 and the thermistor chain deployment location is shown in Figure 2. Measurements made on October 6th and 7th by the glider and thermistor chain are also compared.

The glider temperature profiles shown in Figure 23 are the averages of depth-binned profiles for the entire daily missions, regardless of location in Eastern Passage. The glider profiles for October 6th and 7th are plotted overlaid on a filled yellow area that represents the span of plus and minus one standard deviation at each depth bin. The thermistor chain profiles shown in Figure 23 are averaged over the time periods during which the AML profiler measurements were made (on

October 9th and 16th), or over the duration of the daily glider missions (on October 6th and 7th). The three sets of temperature measurements agree extremely well.

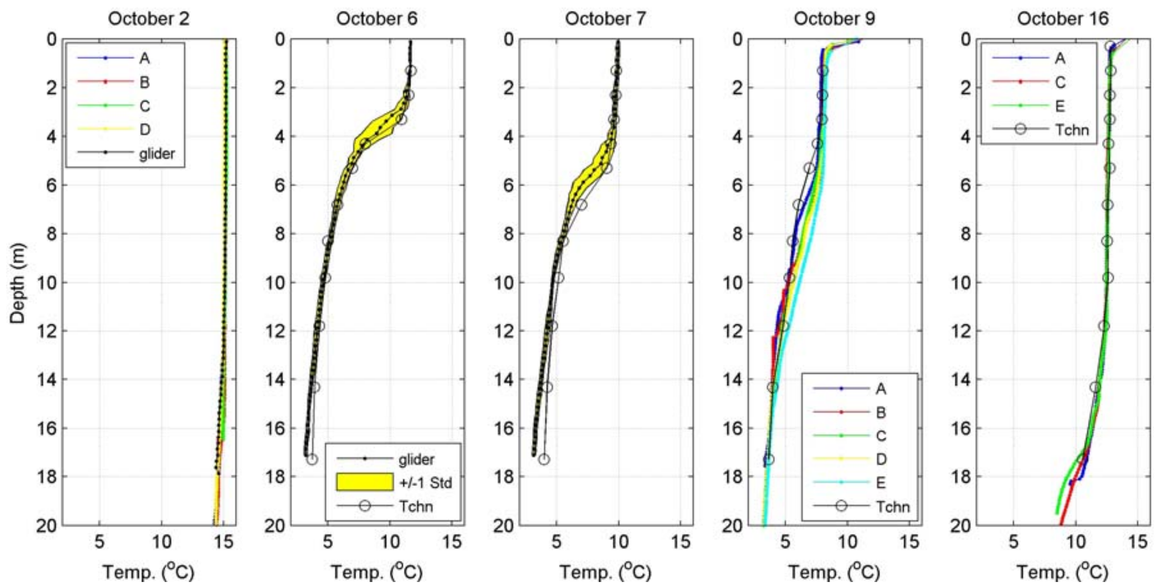


Figure 23: Comparison of AML profiler ("A" through "E"), glider and thermistor ("Tchn") water temperature measurements in October.

The water temperature profiles from all measurements show significant changes over the two-week duration shown in Figure 23. The water column is warm and essentially isothermal on October 2nd. Following a period of strong winds between October 2nd and 6th (see Figure *8*), the deeper water is significantly colder and, more importantly for acoustic propagation, there is a reasonably strong thermocline centred at about 4 m depth on October 6th, which has deepened to about 6 m on October 7th. The thermocline is weakened and near-surface water is cooler by October 9th, with a very shallow warmer layer right at the surface. By October 16th, the vertical temperature profile resembles that of October 2nd with only a small gradient, but is significantly colder. The variability in temperature profiles surveyed by the glider, indicated by standard deviation, is greatest around the thermocline and very small otherwise. This shows there are small variations in the depth of the thermocline across the survey area and otherwise relatively homogeneous conditions on those days.

The effects on acoustic propagation and sonar detection performance of the varying vertical profile over the duration of the trial will be determined when post-trial modeling work has been completed.

5.6 VideoRay Remotely Operated Vehicle Surveys

The site of the DDS deployment was surveyed using a VideoRay micro-ROV on October 15th and 16th. An ROV inspection survey of a deployment can find problems if they exist, such as orientation of the sonar or cable routing. In this case, the DDS had been checked by the divers on deployment, so there was no pressing requirement, however video documentation of the site is always valuable. The ROV pilots were Jeff Scrutton and Paul Shouldice, assisted by Dan Graham (all DRDC personnel). Figure 24 shows a frame from the video recorded on October 16th. The feet of the sonar base and cable are mostly buried in silty material and wildlife has moved in.

Figure 24: Frame captured from VideoRay site survey video recorded on October 16th.

6 Response Boat Operations

The MFP TDP was able to obtain loan of a 7-m Rigid Hulled Inflatable Boat (RHIB) from Maritime Operations Group 5 (MOG5) at CFB Halifax for use as a response boat during the trial. Boat operators (coxswains) were supplied by HMCS Preserver. Figure 25 shows the response boat, fitted and crewed, with imaging sonar deployed from the port side. The crew of the response boat consisted of a coxswain and bow man (CF personnel), an operator for the tactical display and VHF radio, an operator for the sonar pole mount and an operator for the sonar control software. On several days, a guest from the RCMP was on board observing operations.

Figure 25: Barracuda 7-m RHIB outfitted as a response boat.

6.1 Fit-out and Work-ups

The RHIB is one of several "Barracuda" platforms which can be remotely controlled, however this capability was not used during the trial. The Barracuda has a large A-frame for its own radio equipment, and this was used to mount a WiMAX antenna and a GPS receiver. The RHIB was outfitted with a small imaging sonar deployed on a retractable over-the-side pole (shown deployed in Figure 25), two laptops for the tactical/navigation display and sonar control, a battery power distribution system, the WiMAX radio and antenna, and near the end of the trial, an underwater loud hailer system. Fit-out was done in the DRDC compound prior to moving the RHIB to CFB Shearwater. Personnel from MOG5 assisted by transporting the RHIB from the Naval Auxiliary Dockyard to the DRDC compound for fit-out and then from DRDC to CFB Shearwater. Figure 26 shows the WiMAX radio and Hemisphere GPS receiver on the RHIB mast and the sonar pole mount system for the imaging sonars attached to the RHIB port side.

Figure 26: GPS and WiMAX antennas mounted on mast (left) and mounting system for the identification sonar pole (right).

The sonar pole mount system was developed at DRDC during earlier work and has been used before during the Response Against Diver Intrusions (RADI) Joint Research Project trial hosted by NURC in La Spezia in November 2007 and during prior testing at Shearwater and at DRDC's Acoustic Calibration Barge. The pole mount is designed to allow an operator to adjust the pan and tilt angles of the sonar, and to rotate up out of the water altogether while the response boat is transiting. Three small imaging sonars were trialed on the response boat: an Imagenex 837, and Imagenex 881L and a BlueView P450. All were controlled using software running on a Panasonic Toughbook or Itronix laptop (Windows XP) via ethernet and using DC power supplied by a battery system installed in the RHIB for the trial. On the last day of the trial, the response boat also carried the Broadband Acoustic Transmission System (BATS), used as a loud hailer for communicating to divers.

6.2 Response Boat Tactical Display

A component of the integrated force protection system that is being developed within the series of Build cycles is an application for directing the response boat to DDS contacts. Credible detections that are made by a DDS monitoring an exclusion zone must be investigated further and an effective way of directing a response to a detection in a timely manner is required. The Build 1 trial provided the first field test of a rudimentary system that will be further developed during future Build cycles.

The C2 Component of the MFP TDP recently conducted a review of several commercial incident management and "Blue Force Tracking" software products (Kongsberg, Ultra Electronics, BAE Systems, Atlas Elektronik, etc.) [3] and field tested Offshore Systems Ltd. Asset Control Tracking software. None of these were deemed to be suitable for this application. All of these were large, complex systems not easily tailored to the UW Component requirement and licensing fees are considerable. DRDC benefited from the opportunity to observe the US Space and Naval Warfare (SPAWAR) Systems Command Graphical Data Fusion System (GDFS) in use for tasking a response boat at the Response Against Diver Intrusions trial hosted by NURC. Canada does not have access to this software and, like the commercial systems, it is not easily configurable. It was decided to adapt existing route planning software from the Interim Remote Minehunting and Disposal System project that is already owned by DRDC and was developed by MacDonald Dettwiler and Associates (MDA). This provides a configurable light-weight application with the desired features and allows complete control and ownership of the source code.

The tactical display developed during Build 1 has a chart background with overlays of DDS and response boat self position. Figure 27 shows a screen shot of the tactical display and the symbols are described in Table 2. The DDS contacts are displayed with an yellow diver helmet icon and a “Pacman” symbol (shown in red) that indicates the range of suitable approach angles to the contact that prevent the response boat and its wake from obstructing the contact from the DDS.

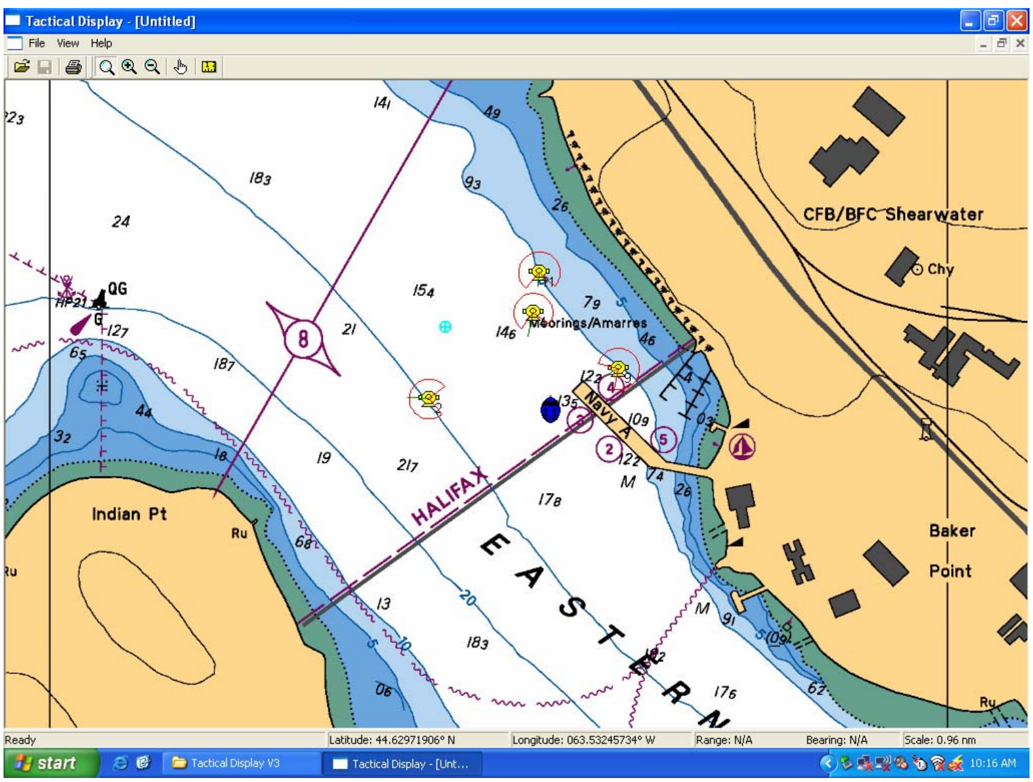
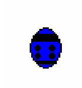
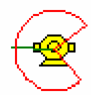


Figure 27: Screen shot of the Build 1 response boat laptop tactical display.

Table 2: Key to symbols on the tactical display.

Symbol	Identified location
	DDS
	DDS contact and range of approach directions
	Response boat self position

During the Build 1 trial, it was found that the tactical display application was prone to software errors that required it to be restarted. This was traced to the libraries for handling the Cerberus messages which had been supplied by QinetiQ. During this first trial of the system, all DDS alerted contacts were being sent across the WiMAX network to the response boat. Plans for future development will filter this information. A shore station application is under development for tasking the response boat to investigate particular contacts or geographic areas, so only those tactical objects will be relayed and displayed.

6.3 WiMAX Network Link Testing

The wireless radio network link is a critical system component connecting the shore station with the response boat tactical display. The system chosen, after consultation with the C2 Component of the MFP TDP, and procured prior to the trial, was a Tsunami 5 GHz WiMAX set. The base station antenna was mounted on the roof of the container on the jetty (see Figure *3*), approximately 10 m above the water surface (6 m above the jetty deck) and the mobile station was mounted on the RHIB about 4 m above the water surface, as described in the previous section. Installation and configuration of the WiMAX system and the subsequent testing reported here were overseen by David Williams (MDA).

Figure 28: Locations of WiMAX data rate measurements plotted on Google Earth aerial photo. The symbol key is given in Table 3 and the yellow circle is 1 km in diameter (figure courtesy of David Williams, MDA).

Table 3: Key for symbols in Figure 28.

Symbol	Base-to-mobile Tx data rate (Mbps)
	9
	6
	4.5
	3
	2.25
	1.5

Testing of the radio link was performed during the trial on October 6th. Response boat position was logged using a Garmin handheld GPS. The radio connectivity is nominally line-of-sight. The response boat travelled from Shearwater North-Westward to the MacDonald Bridge in Halifax Harbour and South-Eastward through Eastern Passage to the North end of Lawlor Island. Locations where measurements were made are shown in Figure 28. The symbols indicate the transmit data rate measured at the marked locations, according to the symbol key in Table 3. The yellow circle in Figure 28 is centred on the 20' container on the jetty at CFB Shearwater and has a diameter of 1 km, the range within which a data rate of 9 Mbps is expected and was achieved.

Figure 29 illustrates a comparison between the measured received signal strength and output from a simple two ray model that uses the base and mobile antenna geometry.

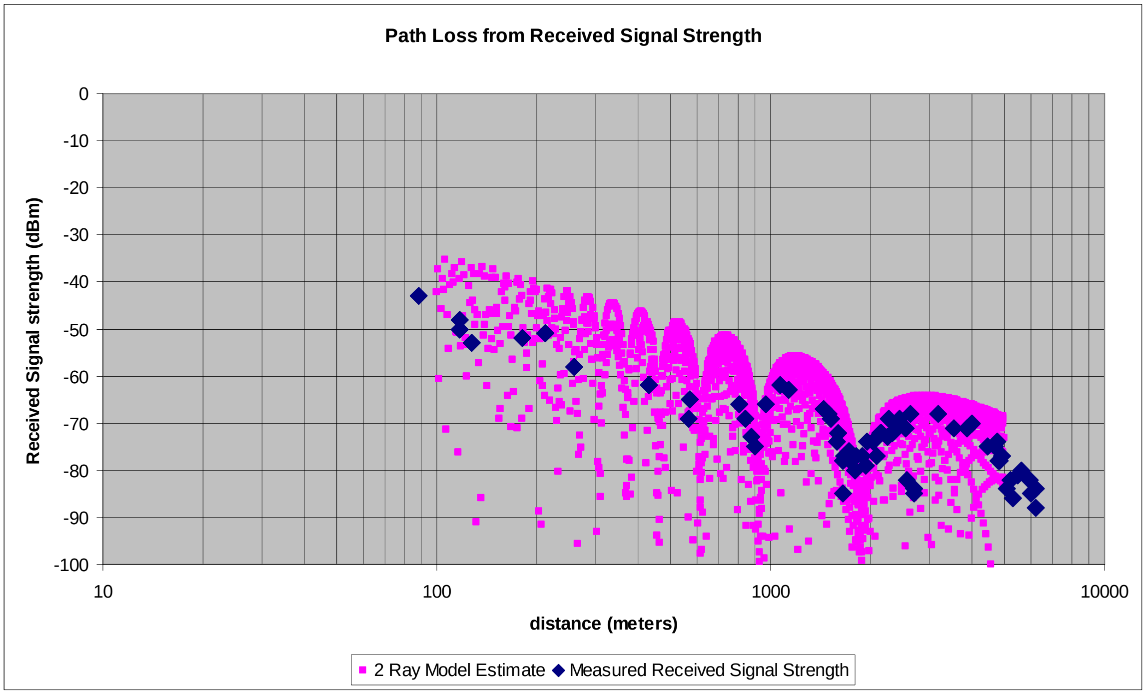


Figure 29: Received signal strength vs. range from model and measurements (figure courtesy of David Williams, MDA).

The measured data rates meet and exceed the requirements for the response boat–shore station communication link. During the Build 1 trial, Cerberus contacts were being sent to the response boat, which is a small volume of traffic, however VNC (Virtual Network Computing, a networked desktop sharing application) was used to send a live copy of the response boat laptop display over the network back to the shore station so that the DDS operators could have access to response boat position. This was a temporary solution which will be replaced when further work on a tactical application for the shore station is completed. The WiMAX network was stable enough and had high enough data bandwidth to support the VNC traffic.

6.4 Detect-to-warn Sequences Against Targets and Divers

A major accomplishment during this trial was the first complete sequences of DDS detection and tracking of a target, through tasking of the response boat via the tactical display and subsequent reacquisition of that target with the imaging sonar. Later in the trial, during the exercises with divers, following reacquisition with the identification sonar, a warning was issued using the BATS loud hailer. Due to the hardware failure in the DDS prior to the diver exercises, complete detect-to-warn sequences were not possible, however the combination of the diver exercises with the prior testing against the floating target demonstrates in principle the vision for the main part of the integrated system under development by the UW Component. The full system will also include tools for prediction of DDS performance with environmental inputs, and this capability is still at an early state of development.

Table 4 gives a summary of response boat operations. Earlier in the trial, practice runs of tasking and acquiring contacts were run against a drifting target (the weighted SCUBA tank shown in Figure 33). The response boat was tasked by transferring DDS contacts over the wireless network to the tactical display and also by radio instruction to the location of the SCUBA tank or diver's float when the DDS had not established a track. For the most part, the targets were approached following the direction of the symbol shown on the tactical display when tasking was done using a DDS contact, however the winds were strong enough on October 7th to make manoeuvring the response boat a challenge. Three imaging sonars were used on the response boat: an Imagenex 881L, an Imagenex 837 and a BlueView P450. During the last two days of operations, October 15th and 16th, the response boat was trialed against FDU divers with closed-circuit breathing apparatus and a scooter diver delivery vehicle. Additionally, on the last day, the BATS loud hailer was added to the system and the tasking was done with the response boat sitting in a standby position near the end of the jetty.

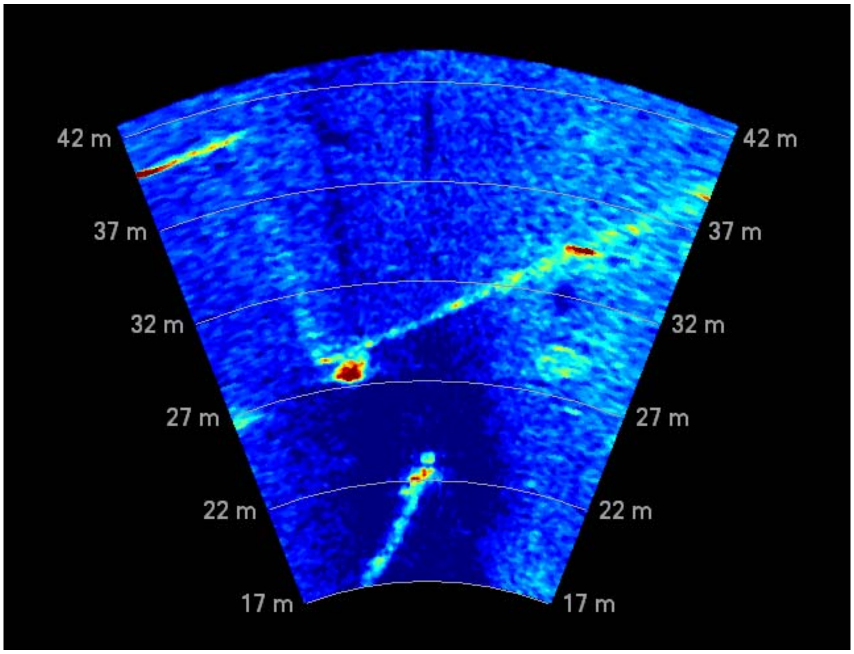


Figure 30: BlueView P450 sonar image of diver (with bubble trail) at 22 m range, approaching the dock.

Table 4: Response boat operations summary, October 7^{th}-16^{th} (times are in UTC).

Date	time tasked	contact acquired	elapsed	Target	ID sonar	Comments
7-Oct				tank	881L	not timed, familiarization & verification that DDS contacts are being x-fered to resp. boat nav display
8-Oct	14:04	14:12	0:08:00	tank	881L	tasked to float location, acquired tank on ID sonar
	14:22	14:25	0:03:00	tank	881L	tasked to DDS track # 347, verified it was NOT the tank, then tasked to float location
	14:51	14:54	0:03:00	tank	881L	tasked to DDS track # 559, acquired tank on ID sonar
	15:03			tank	881L	tasked to float location, acquired tank on ID sonar, no end time recorded
	15:16			tank	881L	tasked to DDS track # 761, acquired, no end time recorded
	15:27			tank	881L	tasked to float location, acquired, then recovered, no end time recorded
14-Oct	16:36	16:45	0:09:00	tank	Delta-T	tasked to DDS track # 1411, acquired on ID sonar
	16:48	16:51	0:03:00	tank	Delta-T	tasked to float location, acquired
	17:03	17:10	0:07:00	tank	Delta-T	tasked to float location, acquired
15-Oct	15:55	17:00		diver	Delta-T	multiple reacquisitions by response boat tailing diver, times not logged
16-Oct	13:30	14:08		diver	BlueView	multiple reacquisitions by response boat tailing diver, times not logged, loud hailer deployed, diver asked to "turn right", diver turned
	15:02:40	15:05:15	0:02:35	diver	BlueView	tasked to float location from standby location at end of jetty, acquired diver on ID sonar, then tailed diver
	15:09:45			diver	BlueView	requested response boat to loud hail diver
	15:10:50			diver	BlueView	diver asked to "turn right", turned
	15:12:30			diver	BlueView	diver asked to "surface", surfaced
	15:20:30	15:24:45	0:04:15	diver	BlueView	tasked to float location from standby position at end of jetty, acquired diver on ID sonar, then tailed diver
	15:25:15			diver	BlueView	loud hailer deployed, diver asked to "turn left", diver surfaced
	15:28	15:32	0:04:00	diver	BlueView	response boat tailing diver, multiple acquisitions on ID sonar

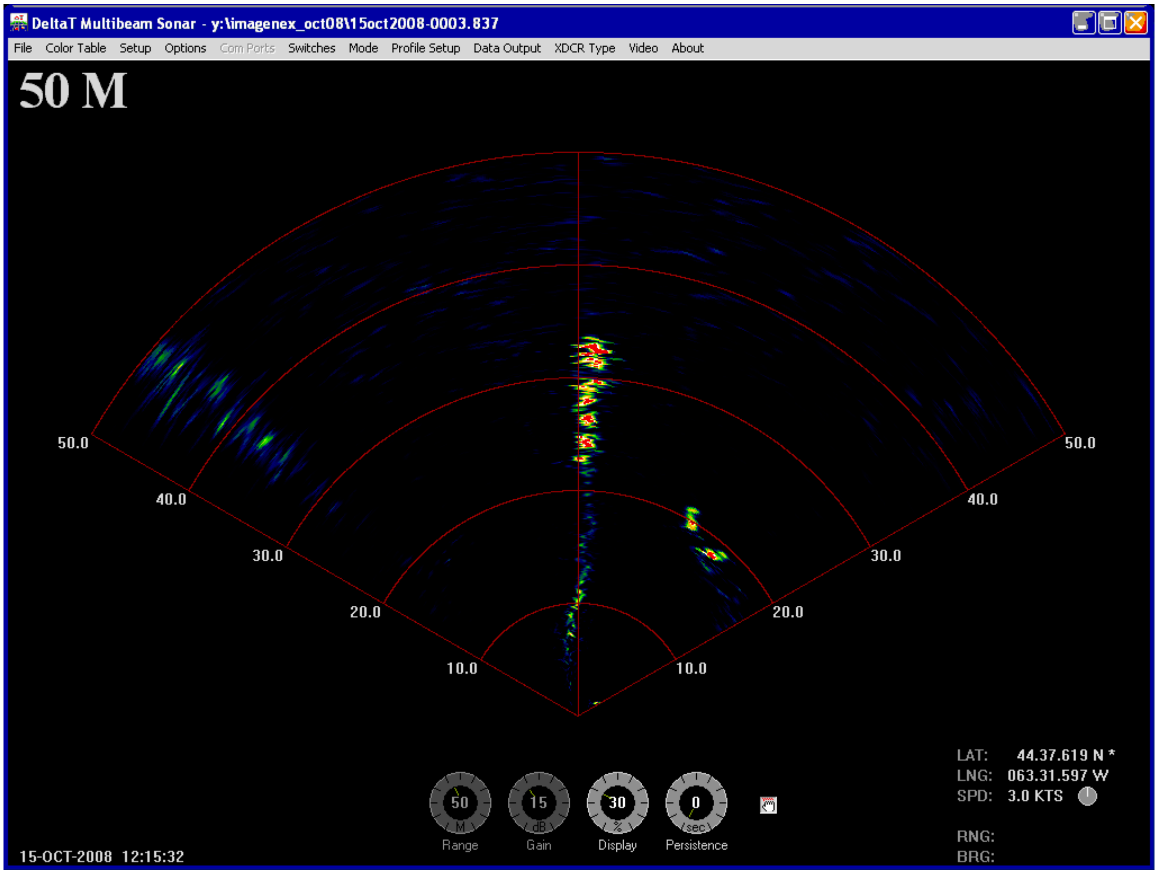


Figure 31: Imagenex 837 image of diver (with bubble trail) at 32 m range, with diver safety boat approaching from the lower right at 20 m range.

The main goal of the Build 1 trial with respect to the response boat systems was to field test the new tactical display and to practice acquiring targets based on the tasking. Since this was the first deployment of the tactical display and wireless network systems, expectations were exceeded. Not enough repeats of the detect-to-warn sequence were accomplished to compile meaningful statistics on quantities such as response time. Valuable lessons were learned, however, which should contribute to significant improvements to the system in the subsequent Builds. Times for tasking and contact acquisition were logged during the final days of the trial, but not rigorously earlier in the trial during the preliminary practice runs. The response time will clearly have some dependence on the distance from the contact to the initial position of the response boat. During the final day of the trial, a stand-by position was established at the North end of the jetty, making the initial distance to the contact between 150 and 500 m. The response boat was capable of travelling at 25 knots with the sonar pole retracted, so transit time was small. In future trials, there should be more complete record keeping of response times and positions to determine if time can be shortened during particular steps in the contact acquisition process.

6.5 Loud Hailer Tests

The Broadband Acoustic Transmission System (BATS) was used as a loud hailer device from the response boat during the last day of diver operations at the end of the trial, October 16th. This system consists of a transducer, a Multi-mode Pipe Projector developed and built at DRDC, and batteries and a power inverter/amplifier packaged in a ruggedized case (shown in Figure 32). It takes input from a standard laptop audio output to play ".wav" file messages.

During several of the reacquisition cycles, instructions were issued to the diver to either turn or surface (see Table 4). On all occasions the diver heard and understood the instructions. The output level on the BATS was set to "10" and typically the range to the diver was 25-30 m.

Figure 32: Broadband Acoustic Transmission System (BATS) used as a loud hailer.

7 Diver Detection Sonar Operations

During sonar operations, an operator manned the DDS and filled out log sheets of events, including times, track numbers, range/bearing to contact and comments. The DDS operator notified FDU Ops by telephone when the sonar was transmitting and when operations were completed for the day. During the last week of the trial, one of several volunteer assistants filled in the log sheets. During response boat operations, tasking and contact acquisition times were also logged, though not rigorously earlier in the trial. The DDS operator or the assistant operated a VHF radio to communicate with the response boat, Zodiac work boat and diver safety boat.

7.1 Operation Time and Logged Data Statistics

The Build 1 trial was the first opportunity to run the newly acquired Cerberus DDS system. Through the month-long duration of the trial, the system was up for over 60 hours. It was transmitting less than half of that time, partly due to a hardware failure that occurred on October 14th. One operator had been trained in the UK during the factory acceptance in August. A second operator was trained during this trial and other team members also gained valuable experience with the system.

Table 5: DDS operation time statistics during the Build 1 trial (times are in UTC).

Date	On	Off	elapsed	Tx time	comment
17-Sep	20:02:38	20:16:41	0:14:03	0:00:00	No Tx, checking DDS sensors post-deployment
18-Sep	14:26:40	16:42:01	2:15:21	2:15:21	
22-Sep	13:28:49	16:19:09	2:50:20	2:50:20	
23-Sep	12:58:26	15:34:00	2:35:34	2:35:34	
	19:54:00	20:45:44	0:51:44	0:51:44	
24-Sep	18:25:08	18:29:16	0:04:08	0:04:08	
25-Sep	13:32:47	19:06:31	5:33:44	5:33:44	
30-Sep	13:04:00	13:07:34	0:03:34	0:00:00	No Tx
1-Oct	20:37:25	21:13:31	0:36:06	0:00:00	No Tx
2-Oct	12:34:55	19:35:18	7:00:23	6:23:23	No Tx for 37 minutes
6-Oct	12:42:04	19:41:53	6:59:49	6:59:49	
7-Oct	12:28:48	18:46:18	6:17:30	6:17:30	
8-Oct	13:12:42	17:58:17	4:45:35	4:45:35	
9-Oct	13:00:43	15:31:47	2:31:04	2:31:04	
14-Oct	12:41:00	18:04:00	5:23:00	5:23:00	DDS hardware failure at 18:04,
	18:30:00	20:32:03	2:02:03	0:00:00	No Tx, troubleshooting DDS failure
15-Oct	12:27:38	18:10:45	5:43:07	0:00:00	No Tx
16-Oct	13:14:40	16:04:00	2:49:20	0:00:00	No Tx
	16:04:00	17:27:39	1:23:39	1:23:00	transmission loss measurements
17-Oct	13:33:06	13:56:49	0:23:43	0:00:00	No Tx, checking DDS sensors pre-recovery
			60:23:47	23:54:12	total up time & total Tx time

The DDS logs several types of data. Tracks and contacts can be recorded and in addition, two levels of sonar data, beam decimated and “raw”. The raw sonar data is not always logged as it takes considerable disk space, though it was logged during some of the target tow and glider runs and while some of the transmission loss measurements were made. The beam decimated data is reduced in size from the raw data (beamformed and decimated) by about 32 times. The system also generates log files while in operation. The disk space requirements for the data logged during the trial are summarized in Table 6.

Table 6: DDS data logged during the Build 1 trial.

Data type	Disk space
Contacts	1.7 MB
Tracks	76.0 MB
Beam Decimated	10915.1 MB
Raw Sonar Data	515.9 GB
Transmit Logs	4.1 MB
Status Logs	0.6 MB

7.2 Target Tow Runs

Several series of target tow runs were performed during the trial to test DDS detection performance and to train DDS operators. The target used was a weighted SCUBA tank suspended about 5 m below a float on the water surface, shown in Figure 33. Initially, the tank was suspended horizontally, but was reconfigured to hang vertically on October 14th so the cross-sectional area would not be aspect dependent. Target tow runs were performed on September 22nd and 23rd, and as part of the transmission loss and environmental measurement cycles performed on September 25th, October 9th, and 16th. The SCUBA tank target was also used as a surrogate diver during most of the response boat operations during the trial by allowing it to drift freely downwind below the float.

Target tow runs were performed on radials centred on the DDS, out and back on several headings, most often toward or back from the channel marker near the North end of McNabbs Island. Runs were also done down the centre of Eastern Passage, across the Passage and following along the jetty 20-30 m off. DDS tracking of the target was observed not to be very good along the jetty, most likely due to the large amount of signal return from the jetty itself crossing over into adjoining sonar beams. On several occasions, large boats travelling down the centre of Eastern Passage left significant wakes which persisted for periods of a half hour or more. The target was not tracked well on the far side of the wake from the DDS. On a run across the Passage toward the jetty that crossed the wake, tracking picked up once the target was clear of the wake on the near side.

Figure 33: SCUBA tank target that was used to test DDS performance.

The target tow runs that were done along with the environmental measurements can be used in conjunction with the hydrophone transmission loss measurements to make an assessment of the target strength of the SCUBA tank. This can then be used to directly assess detection and tracking performance. This analysis has not been performed yet. One difficulty is that the tank was slung horizontally prior to October 14th, so target strength would be varying according to aspect angle to the DDS.

7.3 Diver Runs

As mentioned previously, it was not possible to observe DDS detection performance against divers swimming planned routes as there was a hardware failure of the DDS just prior to the scheduled diver days. On several occasions, "divers of opportunity" were successfully tracked while they were practicing in the "Jack Stay" area near the foot of the jetty (shown in Figure *2* as "Diver Practice Area"). The Jack Stay diver practice area is a rectangular course of rope several meters above the seabed laid out with long sides parallel to the shore between large corner anchors. It is located in shallower water (about 10 m) near the shore, ranging from 200 to 300 m from the DDS. Divers were successfully tracked as they swam along the deeper long side of the course. It is not known whether they were equipped with SCUBA or rebreather gear.

7.4 Spoof Ping Transmissions

The ability of externally generated sonar pings to confuse the DDS was tested by transmitting a series of pings from a transducer lowered from the jetty next to the container. The pings that were transmitted were intended to resemble those from the Sonardyne Sentinel system. The purpose of transmitting Sentinel pings was to test whether there would be significant crosstalk between Sentinel and Cerberus, as future plans include a trial involving both of these systems deployed in close proximity.

It was found that the effects of the spoof pings were dramatic. Thousands of false contacts at all ranges and bearings could be seen on the DDS display.

7.5 Glider Runs

Tracking of the glider by the DDS was not successful, as discussed in Section 5.2. The glider is a small target with aspect dependant target strength, though roughly equivalent in physical dimension to a divers' tank and equipment. Its forward speed is also roughly equivalent to that of an unassisted diver. The glider does not have the associated bubble trail that a SCUBA diver has. A possible explanation for the poor tracking performance against the glider is that it moves vertically through the water column, even though the slope of its track is gradual. There may be enough variation across the DDS vertical beam pattern, and due to propagation conditions, that a consistent contact is not maintained for a long enough time to establish a track.

7.6 DDS Performance Observations

Detection ranges observed during the target tow runs were variable, and generally tracking performance was good. DDS tracks on the drifting target were available to be passed to the response boat to exercise response boat and networked tactical display functionality. Detailed post-analysis of the tracking performance during the target tow runs (using replay of recorded data) has not been performed yet. Specific detection performance values will not be reported here in open literature.

One observation which has implications for future DDS deployments is that it seems that a range limit was set on detection in the North-West direction by a band of strong acoustic interference that originated from a large corrugated metal-clad pier structure on the shoreline to the North of the DDS (Cherubini Metal Works Ltd.). Figure 34 shows a screen shot of the DDS acoustic beam data with the shoreline overlaid in black and the position of the DDS ("Egg") marked. A 40-m-wide band of interference at 500 m range extends more than 100º in bearing to either side of the metal pier. When this screen shot was captured, only the 60º-wide transmit sector directed toward the pier was active. This band of interference was observed to limit detection range to 500 m to the North-West during the target tow runs.

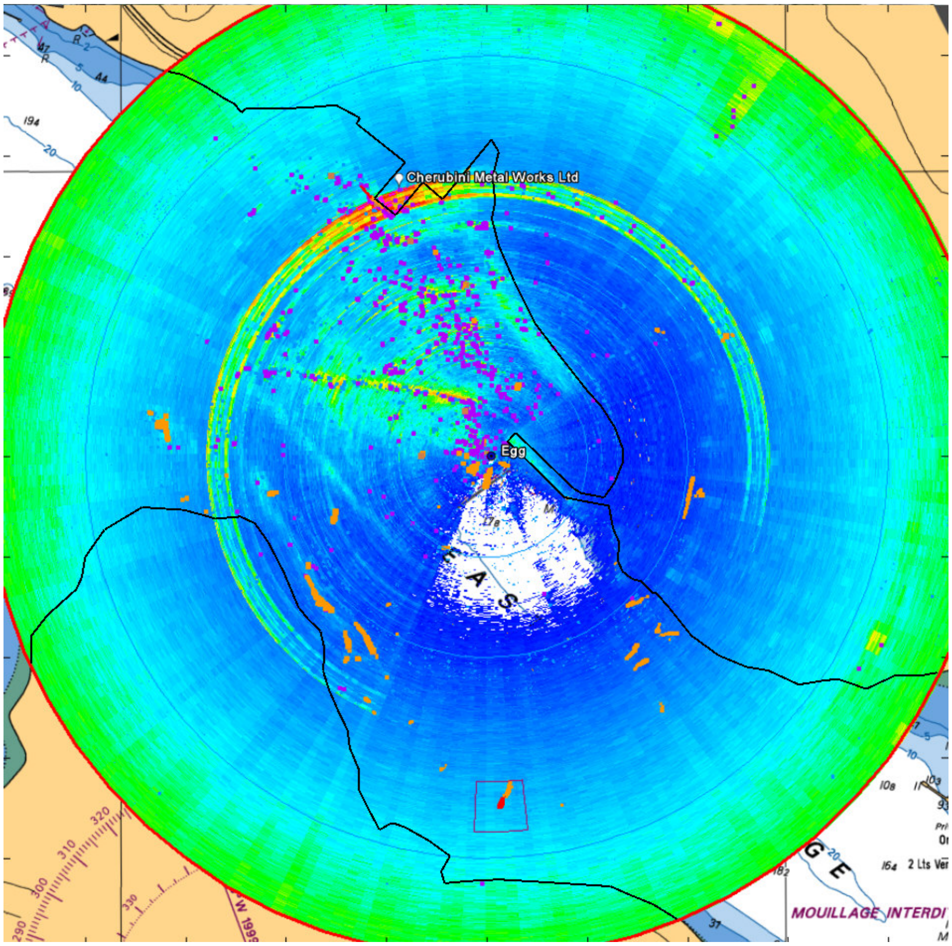


Figure 34: DDS screen shot showing the ring of interference from a metal pier structure.

8 Subsequent Activities

8.1 Diver Detection Sonar Repair and Testing

A hardware failure occurred in the DDS on the afternoon of October 14th. Repair was negotiated with QinetiQ and an engineer, Mr Ben Horton, travelled to DRDC from the UK. The repair work was performed at DRDC. A DC power distribution card in the receiver was found to have failed, and this was replaced along with a wiring harness. The new design for the harness includes some in-line fuses which should prevent a similar board failure in the future. The repair was completed within two days, including opening and reclosing the pressure case. The DDS was then run for several days in the calibration tank on-site at DRDC. It was then transported to DRDC's Acoustic Calibration Barge in Bedford Basin and tested for a further two days. There were no further problems encountered during the testing following the repair.

9 Recommendations

The MFP TDP UW Component program is planned as a series of Builds where incremental improvements are made to an integrated system under development. Several areas of improvement to particular sub-systems were identified during the Build 1 trial. Other improvements follow a logical progression. Several suggestions can also be made about the conduct of trial activities.

The areas identified as requiring improvement in particular systems were mostly related to response boat functionality. These are summarized as follows:

1. Improvements to the tactical display:

    a. General usability: several improvements can be made to the user interface, such as clearer, more visible symbols and larger icons to better take advantage of the laptop touch screen. Hot keys might make it easier for the user to change display settings on a moving platform.

    b. Software stability: during the trial it was noted that the response boat tactical display software froze or crashed, requiring it to be restarted frequently. This has been traced to Cerberus message handling libraries supplied by QinetiQ and should be rectified as soon as possible.

2. Improvements to the identification sonar pole mount on the response boat:

    a. the identification sonar pole mount on the response boat has had several small improvements since it was first fabricated in 2007 and further improvements are required. During the trial, it was found that the rotating collar that allows the unit to be swung out of the water for transit was slipping when the sonar was deployed, preventing the response boat from moving at any more than slow manoeuvring speed without twisting the sonar pole off vertical. It required an operator to continuously man-handle the pole. This is not only labour intensive, but could be dangerous.

The improvements that follow in the logical progression of development of the integrated capability are summarized as follows:

3. Review of manning requirements:

    a. the response boat carried 5 or 6 people during the trial, plus sometimes 1 observer, and 2 people manned the shore station, also with 1 or as many as 3 observers. One comment often heard about operational force protection requirements regards the lack of personnel to assign to this task. An analysis should be done, perhaps in cooperation with the C2 Component, of the manning requirements of the integrated system currently under development. Planned improvements to the response boat systems (tactical display, sonar pole mount) should reduce operator loading and may reduce the manning requirement on the response boat.

4. Development of a shore station for tasking:

   a. this would serve as an intermediary between the DDS and the response boat. A user on shore would select particular DDS tracks to be passed to the response boat, rather than having all the alerted tracks being passed. This would greatly reduce the possibility of confusion and wasted time investigating the wrong track for the response boat operators. Logging capability, for example for tasking actions and times and response boat position, would be an asset.

5. Recommendations for CONOPS:

   a. some thought needs to be put into how this integrated system would best be deployed, again perhaps in cooperation with the C2 Component. To date, no specific consideration of existing CF CONOPS has been incorporated in system development, though there are no existing CONOPS specific to the force protection task. The development of a set of formalized CONOPS is outside the scope of the TDP, however some recommendations could be put forward.

6. Continued development of performance modeling capability:

   a. the modeling capability currently under development was not actually deployed on-site at this trial. A preliminary version has been delivered of a user interface to BellhopDRDC (implemented in Matlab) that includes modules for importing environmental data, along with a tool for viewing beam decimated Cerberus sonar data. This still needs further work. The end goal is to provide the DDS operator with a tool that will show geographic areas of the sonar coverage where detection performance may be compromised by environmental conditions.

Recommendations arising as a direct result of experiences in the planning and execution of this trial are summarized as follows:

7. CF liaison:

   a. arrangements for the loan of the Barracuda response boat and pilot, and for divers' participation in the trial, were made unnecessarily complicated for all parties by the lack of a formal CF channel. For future trials, if possible there should be a designated trial liaison for CF arrangements (preferably a CF member themselves) and these arrangements should be other than verbal agreements.

8. Conduct of trial activities:

   a. Better documentation of event timing and response boat position: where this was the first time that a completely outfitted response boat was tested, expectations were exceeded, however, a better effort in documenting the timing of events and vessel tracks would have provided more usable data on, for example, response times relative to the stand-by position.

b. More rigorous time synchronization: post-analysis of trial data has revealed inconsistencies in timing. The Cerberus system was set to UTC time and the sonar and navigation laptops were on local time. None were properly synchronized.

References

[1] A. M. Crawford, D. V. Crowe, D. A. Hopkin, Maritime Force Protection Technology Demonstration Project Underwater Threats Component Build 1 Trial Plan, DRDC Atlantic TM 2008-189, November 2008.

[2] C. Stone and I. Wolff, General Deployment Procedures for Cerberus Off-Shore Unit (OSU), QinetiQ/S&E/MAC/PROC050848, QinetiQ Ltd, March 2005.

[3] A. Cole, C2 COTS System Survey for the Maritime Force Protection TDP, (LIMITED DISTRIBUTION), report delivered under contract W7707-063601/001/HAL, Macdonald Dettwiler and Assoc., DN0869, March 2008.

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Annex A Cerberus Deployment and Recovery Procedures

This Annex describes the DDS deployment and recovery procedures used for the Build 1 trial. The document was originally prepared by Dana Maxwell, and then edited by Vance Crowe. It draws from a procedures document supplied by QinetiQ [2] and from consultation with FDU(A) personnel who have overseen similar DDS deployments using lift bags. The QinetiQ procedures assume deployment and recovery are performed from a floating crane barge. The procedure described here uses a shore-side crane on the jetty and a large lift bag supplied by FDU(A).

SOP for Deployment and Recovery of Cerberus Diver Detection Sonar

The sea bed deployment of the Cerberus360 diver detection sonar (DDS) system is split into 3 phases. Section 1 covers the preparation of the equipment, section 2 details the deployment procedure and section 3 details the Cerberus recovery procedures.

1 Preparation for Deployment of Cerberus DDS

The following equipment will be required:

1. Cerberus360 Off-Shore Unit (OSU) with Adjustable Base
2. Cerberus Umbilical cable (30 cm minimum bend radius)
3. 5/8" lifting shackles
4. Rope or Kellum Grip
5. Cable Ties for mousing
6. Spirit level for checking vertical

Prior to the deployment of the Cerberus OSU it is suggested that the following actions be undertaken:

1. If possible, a sea bed survey to show bottom profile along with a sample of the bottom material. As a minimum, the depth of water at the deployment site should be known and the installation site and umbilical cable route should be checked by a dive team for new obstructions.
2. A suitable location for the shore-side breakout box be identified, and the shoreside route for the umbilical cable be checked.
3. Location of suitable dockside crane or mobile crane unit. Ensure that the mobile crane to be used has sufficient height to correctly deploy the Offshore Unit in the required depth of water.

If the Cerberus unit is not fitted to its base, the following procedure will have to be carried out prior to deployment.

1. Attach shackle and lifting strop to the lifting eye of Cerberus. If the Cerberus unit is to be deployed immediately then use the deployment strop/ rope.
2. Lift the Cerberus OSU until it is lined up with the upper flange of the base.
3. Lower and align the Cerberus OSU to the adjustable base upper flange until two of the securing bolts (M20 x 50mm) can be started.
4. Secure the Cerberus unit to the adjustable base using all 8 of the fixing bolts, using washers and spring washers. For a more permanent attachment, a solution such as "Loctite Threadlock" or “NeverSieze” as appropriate could be used.

Figure 1 - OSU end of the Cable and Rope Grip

2 SOP for Deployment of Cerberus 360° DDS.

While handling the umbilical cable, at all times ensure that the cable does not snag or get overly bent (minimum bend radius = 30cm)

D1. *Position* the OSU installed on its base on the quay at a suitable point for lifting by the dockside crane. At this stage, it is assumed that the umbilical cable is not connected to the OSU.

D2. *Attach* a lifting strap and float bags to the upper lifting eye of the Cerberus OSU and mouse the shackle(s).

D3. *Connect* the free end of the umbilical cable to the OSU connector. Place the umbilical cable and spool in position for a smooth deployment and minimal handling. Do a power on – rub test if desired. Ensure source level set at -24dB before enabling. Turn power off. *Disconnect* the shore side of the umbilical.

D4. *Protect* the umbilical cable by using a Kellum / rope *grip* in the vicinity of the OSU connector. See Figure. Attach the eye of the grip directly to the hole in the base unit or by using a shackle. Mouse the shackle if used.

D5. *Attach* the lifting strop to the crane hook and *lift* the OSU clear of the quay. Taking care of the umbilical cable, swing the OSU outboard of the quay. Lower the unit into the water.

D6. *Add air* to the float bags until the unit is *supported* by the floats rather than the crane. The dive team shall monitor the umbilical and lift components.

D7. *Tow* the Cerberus slowly into position and pay out umbilical cable from the jetty making sure there is slack.

D8. *Lower* the unit once in position by slowly *reducing* the amount of air in the floats until the OSU becomes negatively buoyant. Divers will guide the Cerberus to the sea bed.

D9. Add any weight ballast required for tide or currents. Divers to use a level to check the vertical alignment of the OSU, adjust if necessary. *Remove* the floats and excess shackles from the OSU.

D10. The dive team should *check* the lay of the umbilical cable back to shore.

D11. *Connect* umbilical cable to the shore-side breakout box (BOB) and secure.

D12. Once divers are clear of the unit (25m), *power up* the Cerberus360 Unit and check the DDS system including compass and tilt sensors for vertical alignment. If the system requires vertical adjustment, ensure that all power is off prior to the divers returning to the OSU.

Cerberus Umbilical Cable minimum bend radius is 30cm

3 SOP for Recovery of Cerberus 360° DDS

While handling the umbilical cable, at all times ensure that the cable does not snag or get overly bent (minimum bend radius = 30cm)

1) Ensure all power to the Cerberus360 system is off.

2) Attach float bags to the OSU.

3) Dive team to take care of the umbilical cable in the water ensuring the cable is not overly bent or snagged.

4) Shore team pull in cable as required during lift and recovery

5) Add air to the float until the Cerberus becomes buoyant.

6) Once at the surface, attach a tow rope, and tow the OSU into position for the crane to lift. Shore staff recovers the umbilical while the OSU is being moved.

7) Maneuver the crane into position above the OSU.

8) Lower the lifting strop down to the Cerberus OSU.

9) Divers attach the lifting strop to the OSU and mouse the shackle.

10) Lift the OSU

11) Lower the OSU on to the quay

12) Disconnect the umbilical cable from the OSU and recover onto its storage drum.

Cerberus Umbilical Cable minimum bend radius is 30cm

List of symbols/abbreviations/acronyms/initialisms

ADCP	Acoustic Doppler Current Profiler
AML	Applied Microsystems Ltd.
AUV	Autonomous Underwater Vehicle
BATS	Broadband Acoustic Transmission System
C2	Command and Control
CF	Canadian Forces
CFB	Canadian Forces Base
CONOPS	CONcept of OPerationS
CTD	Conductivity-Temperature-Depth
DDS	Diver Detection Sonar
DRDC	Defence Research and Development Canada
FDU(A)	Fleet Diving Unit (Atlantic)
GDFS	Graphical Data Fusion System
GPS	Global Positioning System
HMCS	Her Majesty’s Canadian Ship
MDA	MacDonald Dettwiler and Associates
MFP TDP	Maritime Force Protection Technology Demonstration Project
MOG5	Maritime Operations Group 5
NURC	NATO Undersea Research Center
RADI	Response Against Diver Intrusions (trial)
RCMP	Royal Canadian Mounted Police
RHIB	Rigid Hulled Inflatable Boat
ROV	Remotely Operated Vehicle
SCUBA	Self-Contained Underwater Breathing Apparatus
SPAWAR	Space and Naval Warfare Systems Command
UK	United Kingdom
UW	Underwater (Component of the MFP TDP)
VHF	Very High Frequency (radio band)
VNC	Virtual Network Computing (computer desktop sharing system)
WiMAX	Worldwide Inter-operability for Microwave Access (wireless network technology)

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The Maritime Force Protection Technology Demonstration Project (MFP TDP) is on-going at DRDC Atlantic with the objective of providing advice to the CF on force protection issues by examining requirements, state-of-the-art solutions and capability gaps, while conducting a series of tests and evaluations on developmental and COTS equipment. The Underwater Threats (UW) Component focuses on addressing deficiencies in current CF capabilities for countering underwater threats to Canadian ships in harbours and anchorages. The UW Component program is designed as a series of three Builds, each including a trial, incorporating incremental improvements using a spiral development approach. The first Build trial was completed at CFB Shearwater, Fleet Diving Unit (Atlantic), in October 2008. This was the first field test of an integrated capability that includes a QinetiQ Cerberus diver detection sonar (DDS) purchased as part of the project, and a response boat outfitted with a tactical navigation display and high-frequency identification sonar for investigating targets tracked by the DDS. A major accomplishment during the trial was achievement of complete detect-to-reacquire sequences where a target was tracked by the DDS, the track location was transferred to the response boat tactical display via wireless network, and that target was reacquired with the response boat identification sonar. During exercises with divers, an underwater loud hailer was deployed after contact acquisition, a warning was issued and diver response observed. A comprehensive acoustic environmental data set was obtained during the trial which will allow further development of a DDS performance prediction tool which is also a component of the integrated capability under development.

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